ANIMALS LOOKING INTO THE FUTURE

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ANIMALS LOOKING INTO THE FUTURE

BY

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To the most potent factors in my personal development:
MY WIFE, LIDA HOOPER KEPNER, AND
MY CHILDREN, BETH, HOOPER, AND LIDA.

PREFACE

The students of the University of Virginia have recorded in verse the tradition that their professors, in the early days of the last century, used to appear on the moonlit "Lawn" in night clothes and dolefully chant, as they danced, "We know it all; we know it all; we've sought for more in vain; we know it all!" The marvelous advance in knowledge during the nineteenth century encouraged the student bodies of institutions everywhere to think that perhaps their respective faculties really did have the key of the Universe in their respective vest pockets.

The twentieth century, I think, will be concerned with discovering what is real behind all of the new knowledge acquired in the previous century. In the testing of this knowledge and the theories arising therefrom, the obvious facts and relations will play a large part. The statement that animals look into the future will seem obvious to the reader, and yet this is one of the evident things, in nature, concerning which the biologists of the nineteenth century took little notice. This book is written to emphasize this conspicuous feature of animal conduct, because preparing for the future is a highly significant characteristic of vital activity which is all too often overlooked at present.

The average person deals with obvious matters, as he does with the air he breathes, and he fails to recognize their importance until it is emphasized. Poets, for example, in one line of verse may recognize the obvious fact that animals look into the future and in the very next lines ignore it. Burns did so when he wrote:

"Still thou art blest, compared wi' me!
The present only toucheth thee:
But, och! I backward cast my e'e
    On prospects drear!
And forward, though I canna see,
    I guess and fear."

But mice have plans. That mice and men have plans is significant. Sticks and stones have never had well-made plans. This book seeks to emphasize the difference between mice and men as over against sticks and stones. In this emphasis lies my main purpose.

But I have a second object in mind in this effort. I desire to let it be seen that the facts of biology carry us beyond what the mind of man may hope to understand. Teachers of biology "should realize, like the amateur, that the organic world is also an inexhaustible source of spiritual and esthetic delight. And especially in the college we are unfaithful to our trust, if we allow biology to become a colorless, aridly scientific discipline, devoid of living contact with the humanities. Our intellects will never be equal to exhausting biological reality."[1] My second object is, therefore, to interest the undergraduate students of biology and cognate subjects, as, for example, psychology and philosophy, in the "biological reality" that carries one beyond that which occupies space and which can be measured or predicted.

I have been helped by my wife, who by reading and criticism aided greatly in shaping the manuscript and who later took a large part in the preparation of the index. My colleagues of the summer of 1924, Dr. Bruce D. Reynolds, Mr. Conway Zirkle and Mr. D. L. Hopkins, rendered me valuable service in criticising

[1] Wm. M. Wheeler, "The Dry-rot of our Academic Biology," *Science*, 1923, Vol. 57, p. 70.

the final draft of the manuscript. To Miss Nancy Gordon, of the Miller School of Biology, I am grateful for much aid in preparing the manuscript for the publishers. Dr. Bruce D. Reynolds has lent me his drawing from which figure 36 was made. Figure 70 is a close, but not exact, copy of Dellinger's figure. Wilhelm Englemann, of Leipzig, Germany, has let me use figure 71. The Columbia University Press has given me permission to use figure 51. And I am indebted to Henry Holt and Company for figures 35 and 67; Science Press for figure 1; Ginn and Company for figure 2; and The Carnegie Institution for figures 23 and 46. The Macmillan Company has allowed me to use figures 5, 19, 20, 21, 27, 39, 40, and 41. To all of these publishers I am grateful. Finally I wish to acknowledge, in a special manner, my appreciation of the counsel, cooperation and efficient service rendered me by The Macmillan Company as the book was being published.

WM. A. KEPNER.

UNIVERSITY OF VIRGINIA,
MARCH, 1925.

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CHAPTER I

MAN LOOKING INTO THE FUTURE [1]

Man is the most prescient of all animals. He seeks his welfare, as a rational animal on land, in air, upon and in the soil and waters of the earth; he makes the ether of space his messenger and dreams of splitting atoms in order to harness great stores of energy.

So varied have been the lines along which his rational prescience has taken him, that to follow them would mean the tracing of human history as a whole.

It is, therefore, our purpose to see what man's seeking his fundamental welfare, as an animal, has resulted in. Plants like animals must have food and drink, respond to stimuli and propagate themselves. Water is available to both plants and animals. For this they need not go far. So likewise the materials upon which typical plants feed are found on all sides about them. But it is not so with typical animals. They must seek their food. The differences to be seen between plants and animals arise out of

[1] The reader will please bear in mind that I am writing for the layman. The phrase: "Looking into the future," and such words as: "prescience," "realize," "learn," "choice," etc., are not to raise the implication that there is self-consciousness behind the animals' conduct as there is behind human conduct.

the fact that a plant does not have to travel about after its food while an animal does. The search for food, therefore, becomes to all typical animals a fundamental concern. Even for man the search for food is fundamental.

Man's search for food throughout his racial history has been so insistent as to have become the dominant factor in his evolution. Mark Twain, in saying that the human race is a "Damn race," may more epigrammatically define the human race than a biologist; but biologically man must be characterized as the most persistent seeker of food extant.

He was not always thus. Primitive man did not live on the fat of the land. Tyler (21) says "We may imagine primitive man as having become fairly well accustomed to life on ground, and as having mastered the first lessons in meeting its dangers and difficulties." P. 18. There were, no doubt, dangers and difficulties. There must have been other animals living and competing with these men, that were more highly specialized and better adapted to fight for the best foods. Then, too, some of the animals attained an instinctive prescience far superior to what rational men had yet acquired. We may picture the instinctive contemporaries of primitive, but rational, man as excelling in many respects in the problem of securing and maintaining a food supply. Under these conditions man had to be content with what food the cunning of his dawning mind, aided by a more or less naked body, could acquire.

Even legendary history does not picture early man as being provident. The various allegories of these men picture them as being supplied with all the

necessities of life, who later, however, came to grief and had to struggle for their food and earn their bread by the sweat of their brow.

Whether we take the scientific or legendary picture of early man we find him confronted eventually with an urgent struggle to establish a more extensive and certain food supply. Ultimately man came to see, what the instinctive animals as a whole did not discover, that his security of food depended upon the welfare of plants. If he is to live, plants must also live. If he is to have abundant food, plants must abound plentifully.

When men first turned towards tilling the soil and collecting seeds for sowing, they stood at the transition between the foraging, hunting age and the line of men that has led down to our modern civilization which is based upon agriculture and not the chase.

Ages must have passed when man did little more than clear a plot of land for seeding and then see to it that weeds were kept out of their crops. But our earliest records of human civilization show that this transition from hunters to agriculturists had been passed when these were written. The civilization of the Babylonians, Egyptians, Romans, and Israelites were based upon agriculture that involved tillage of soil. These ancient peoples provided manures and irrigation for their lands. The latter had a law by which "the seventh year's fallow prevented the exhaustion of the soil, which was further enriched by the burning of the weeds and spontaneous growth of the sabbatical year." (Enc. Brit. 1, p. 388-d.)

Modern civilization cannot afford to have its agricultural lands lie idle for a year; nor can it afford to

have the fertility of its soil exhausted. Immense guanin beds are being exhausted in order to maintain the fertility of modern farm lands. Nitrogen-fixing bacteria, living symbiotically with legumes, are being employed to increase the available supply of nitrates in the soil. Finally, immense power plants are being operated whereby nitrates are formed from the nitrogen of the air. As this scource of nitrates becomes more developed, depletion of the Chili's guanin beds will become less serious. Lime and phosphate-bearing rocks, manure and other animal products are also appropriated as soil foods. So well can modern man take care of soil that, though intensively cultivated, it will not deteriorate. For example, some soils in Europe have been farmed intensively for more than a thousand years and yet their fertility has not been impaired.

In turning from the chase to the soil and its tillage man changed from a collector of trophies to a collector and selector of seeds. At first, no doubt, men simply held over a batch of collected grains for seed. Eventually, however, men fell upon the idea of selecting seeds from the best plants and then again choosing the best seeds that the best plants yielded. Thus Neolithic man may be thought of as "noticing the big seeds of Hermon grass, gathering some of the heads, breaking the brittle spikelet-bearing axis in his fingers, knocking off the rough awns or bruising the spikelets in his hands till the glumes or chaff separated off and could be blown away, chewing a mouthful of the seeds —and resolving to sow and sow again."[1] As with wheat, so with other wild plants that attracted the

[1] "Outlines of Science," J. A. Thompson, Vol. I., p. 190.

attention of early man, selection of seed and cultivation has brought them up to a point of great utility as food-plants. So greatly have they shaped these plants with reference to the needs of men that in many cases they cannot be recognized as being related to the plants from which they had been bred. Despite this advance made through random seed selection, little real progress had been realized until the nineteenth century. Prior to the world war, England had increased the value of her wheat crop by three million pounds by selecting, in a series of Mendelian experiments, a homozygous recessive strain. This yielded a wheat that was beardless and at the same time immune to rust. In this connection it is of interest to note that "one of the factors that assisted the Allies in overcoming the food crisis in the darkest period of the war was the virtue of Marquis Wheat, a very prolific, early ripening hard red spring wheat with excellent milling and baking qualities. It is now the dominant spring wheat in Canada and the United States, and it has enormously increased the real wealth of the world in the last ten years (1921). . . . In 1917 upwards of 250,000,000 bushels of this wheat were raised in North America and in 1918 upwards of 300,000,000 bushels; yet the whole originated from a single grain planted in an experimental plot at Ottawa by Dr. Charles E. Saunders so recently as the spring of 1903."[1]

In turning to the soil man did not become herbivorous. While Neolithic man may have gathered the seeds of Hermon grass and garnered the harvest from his planting, he also must have been killing wild animals about him for his food. Perhaps he had already domes-

[1] "Outlines of Science," J. A. Thomson, Vol. I., p. 191.

ticated the dog to aid him in hunting down other wild animals. In time man came to training large animals like the horse, camel and elephant to aid in searching for food. Other animals were domesticated and reared to provide milk and meat. Along this line, too, considerable progress has been made. It would be difficult, for example, to learn with certainty what the wild ancestors of our various domesticated animals were. In this line of agricultural effort, great progress has been made in recent times through the control of disease and the application of scientific principles of breeding. Vast herds of highly perfected sheep, hogs and cattle throughout the temperate regions of the world now help maintain a secure food supply for the human race.

The extensive cultivation of plants and animals could not be carried on as it is in the present day, were it not for the great progress man has made in mechanical methods of tilling the soil, of cultivating crops, and in the preservation and transportation of plant and animal products.

When man discovered the advantage gained in using an implement, his prescient powers were widened. A creature, not knowing the advantage of a heavy club will not venture as far in quest of prey as will his fellow that has learned to wield a cudgel. Man has existed as an implement-using animal for at least four hundred thousand years. As far back as that there lived in Europe the Foxhall man—"capable of making ten or twelve different kinds of flint implements, of providing himself with clothing and of building a fire."[1]

[1] "Recent Discoveries of the Antiquity of Man." By H. F. Osborn and Chester A. Reed, *Science*, Sept. 1922, p. 256.

These men with their crude tools and their fire had already entered a phase that has culminated in our modern mechanical age. The Foxhall man set out with arrows, axes and other flint implements to search for food while modern man tills the soil with powerful tractors and plows, harvests the crop with still more machinery in order that he and great herds of stock may be supplied with food. His machines and knowledge of the process of decay enable him to preserve the food of all climates, while his powerful engines of transportation carry food to all quarters of the earth.

Thus through the development of husbandry and mechanical transportation, prescient man, as organized in the leading nations of the world, has come to maintain so firm a grasp on his future food supply that famine does not threaten him.

Despite civilized man's relative security with reference to his future food supply, he is not independent. He is as distinctly dependent upon the plants about him for food as were the first men. Humanity yet depends upon the photosynthesis of plants for its basic food supply.

Chemistry, however, may be indicating a way of emancipation from this dependence upon chlorophyl-bearing plants.

Professor Moore in 1915 showed how a reaction similar to those of chlorophyl in photosynthesis could be obtained by the substitution of certain inorganic salts for chlorophyl. In this substitution iron salts are the most effective and the results are most conspicuous when there is a maximum of colloidal surface presented. Again in 1911 "Stoklasa and Sdobnicksy made the remarkable discovery that by the action of

ultra-violet light on nascent hydrogen and carbon dioxide sugar was formed." In discoveries such as these, G. H. Parker sees suggested "the means by which we are to throw off our slavery to the green plant" and he is convinced that our staple foods will be products of the biological chemist.

So just as man's turning in his prescience from the chase to the soil freed him from the limitations imposed by the life of a hunter, so his turning from agricultural effort to chemical endeavor may carry him into a wider realm of freedom.

Emancipation, however, is dangerous biologically. For just as the Amoeba remains an Amoeba to the degree in which it has escaped the enforced struggle of higher animals, so progress of man will cease if mere emancipation from the sordid care of plants should ensue. This emancipation should be realized, therefore, only when man is prepared to be subjected to some unavoidable effort of an higher order.

CHAPTER II

SOCIAL INSECTS LOOKING INTO THE FUTURE

An insect's prescience is instinctive. Each insect begins its task where its parents took up their work. Therefore, an individual insect does nothing strikingly original. So pervaded with racial knowledge does an ant appear to be, that it profits little by its experiences as an individual. The insects represent a line of organic development that has been guided by racial knowledge. They, therefore, are not found doing such things as a bear was seen to have done. This bear was with his fellows in a bear-pit of a Paris zoölogical garden. One cold morning Mr. A. H. Tuttle thought he'd try to induce the bears to plunge into the cool water of the pool that was in the pit. He found only one bear interested in the food that he had to offer. In an effort to get him into the water, Mr. Tuttle would throw a piece of cake near the pool's side that was farthest away from the bear. This was repeated from various positions, but in each case the bear, instead of getting into the water and swimming directly for the food, would walk around the wall to where he could lift the cake from the water with a front paw. Finally, a piece of cake was thrown near the middle of the pond's rectangular surface. In this position the bear could not reach it from any side. The animal then displayed a remarkable power to use his own individual experience; for he went to the corner of the pool remotest

from which the food was floating, and by putting his front paws apart on the two corner walls, dipped his head and neck beneath the water and swayed to and fro. After this was done he sat up and watched the cake as it drifted before the waves he had thus set up. When it had drifted to where he could reach it he went for it and took it out with a paw. In this remarkable conduct he had made use of his own observation that objects in the water drift before waves and that he could set up waves in the water by his body's being moved within it. To my knowledge no insect has ever been seen doing a thing so original as this. But even for bears, that stand as representatives of a line of development that has culminated in man, this was a remarkable demonstration of rational prescience. But how far beyond this may man look! He now pictures for example, that when our earth's temperature shall have sunk to the temperature of the moon, "our atmosphere will then be liquid air, thirty-five feet deep, lying upon the solidly frozen masses of our water-ocean."[1] The social insect's conduct, in contrast to the conduct of the bear and man in general, tends to be more communistic.

Where instinctive prescience has been highly developed among social insects there has resulted a highly complex social organization. The honey-bee, for example, in providing for the propagation of its race and its food supply, has become highly organized as a colony. In a beehive there are to be found three types of bees: one queen (a fertile female); some males (drones) and many workers (sterile females). A racial consciousness seems to dominate the hive. In it no

[1] "The Outlines of Science," J. Arthur Thomson, Vol. I., 1922

evidence of anything akin to the self-consciousness of man is seen. As a result, the integrity of the individual in social instinctive animals is broken in upon to a degree that may not be possible in human society where self-consciousness looms up as a most marked characteristic. We see, therefore, a worker honey-bee so highly specialized that it is not able to take part in propagating the race. All the efforts of the individual worker are bent toward the welfare of the colony and race.

This distinction between evolution among instinctive animals and that of rational man becomes more conspicuous when one studies the composition of a colony of leaf-cutting ants.

Before I can tell of the highly remarkable prescience shown by these colonial insects, their colony organization should be given.

Just as in a colony of bees there are drones, workers, and a queen, so in a colony of *Attas* these same types of individuals are present.

The drones in each colony are the least interesting. These are the males. The male honey-bee is not adapted to collecting honey and pollen and secreting wax. He must be tolerated in order that the species may be maintained. And but toleration it seems to be that is meeted out to him by the workers. For when his kind become too numerous, or when his services are not needed, he is driven from the home or killed. The *Atta* male likewise plays but little part in the life of the colony and escapes with little work. He is not fettered to the ground as are the other members of an *Atta* community, for he does not suffer the loss of his wings. And without suffering or enjoying

the enforced effort, that a dealeated (wings cut off) condition imposes, the male *Atta* has departed least from the ancestral type in that he, of all the members of the colony, is least specialized. His chief function in the colony is to insure the ensemination of the queens, (i. e. queens' receiving sperm-cells) when they leave the colony in a "marriage flight." Incidentally it would be interesting to know whether the male *Atta* is developed from an unfertilized egg and has therefore but half as many chromosomes in a given cell as does a worker or a queen.

The sexual complement of the male is the female known as the queen. The queen is the largest individual of the colony. She during her early life is the most powerful, aggressive, and independent of all *Attas*. But by the time the colony has been established, she has lost her wings, is waited upon in all respects by the workers and has reverted to little more than a reflex egg-laying machine.

Two types of individuals in the colony of *Attas*, the males and queens, function primarily, therefore, for the maintainance of the species. In the division of labor that has taken place in the evolution of *Atta* society they have been appointed the bearers of the germ-plasm.

The immediate care of the individuals of a colony and their food supply depend upon the sterile females, which correspond to the workers of a colony of bees. The workers of an *Atta* colony, however, are of three grades. These grades are not clearly demarked but they may be referred to as the largest, medium, and smallest sterile females.

The largest sterile females are known as the *Maxims*.

They have powerful bodies backed by highly pugnacious dispositions. They are always ready to attack any unusual invader of the nest. The vise-like grip of their jaws is so highly reflex after the mandibles become fixed, that though the remainder of the body be torn away the head will cling to the bitten object as it is anchored by the clinging mandibles. William Beebee records the following: "The mechanical, vise-like grip, wholly independent of life or death, is utilized by the Guiana Indians. In place of stitching up extensive wounds, a number of these giant *Atta Maxims* are collected, and their jaws applied to the edges of the skin, which are drawn together. The ants take hold, their bodies are snipped off and the row of heads remains until the wound is healed."[1]

The sterile females of intermediate size are called *Mediums*. They play an important part in the colony's prescience concerning its food supply. It is they that, throughout the working season when rain and heat do not prevent them working, gather and prepare the soil upon which the *Atta's* food must grow. This soil or culture medium is composed of fragments of leaves. The *Mediums* in great numbers leave the nest, travel out to some leaves on a plant and then each *Medium* cuts out a fragment that will not be too large to drag back to the nest. Here the fragment will be delivered to other *Mediums*. William Beebee has seen around one bit of green leaf "five *Mediums*, each with a considerable amount of chewed and mumbled tissue in front of" her.[2] This triturated tissue, as we shall see later, is to be the soil or culture medium upon which

[1] "The Attas at Home," Wm. Beebee, *Atlantic Monthly*, 1921, p. 629.
[2] Ibid., p. 629.

the specific food-plant of the *Attas* grows. These little instinctive farmers in their prescience have thus a more arduous task than has man, the rational farmer; for while the latter must till, fertilize, and sow his soil, the *Atta* must find, carry home, prepare, and seed her soil.

In itself, the method of collecting and preparing this soil is not remarkable; for the leaves are handled as are the fragments of leaves upon which other leaf-cutting insects feed. The unusual feature of the *Atta's* procedure is that the *Medium* does not swallow the triturated leaf-substance, but lays it aside to be used as a soil or culture medium upon which the colony's food supply depends.

The duty of the *Minims*, on the other hand, is not only unusual but remarkable. As sterile females, their individual experiences can in no manner influence the germ-plasm as it flows on through successive generations. Then, too, the bearers of the germ-plasm seem to have little to do with the tasks of these smallest sterile females. And yet, despite the fact that their experiences cannot be reflected upon the stream of germ-plasm, the *Minims* do the most careful work of the colony in the matter of maintaining a food supply. They must grow the food for the colony. Their methods of cultivating their food plants are quite refined.

A farmer, in tilling his field of corn, takes care to keep down all other vascular plants that might compete with the corn plants. He takes no notice of the inconspicuous fungi that may locally infect these plants and gives little attention indeed to the conspicuous smut. The *Minims* have to deal with the subtle true and false fungi known as molds and bacteria respec-

tively. The ants as they come into the nest must bring in the spores and even hyphae of many undesirable fungi and likewise carry bacteria. These undesirable fungi might compete with the *Attas'* food-plant, while the bacteria might cause fermentation on the leaf-pulp and thus defeat the labors of the *Mediums*. It is against these "weeds" that the *Minims* must work. They handle "weeds" that a farmer would overlook and in their work suggest the care that a bacteriologist takes in developing a "pure culture" of bacteria. That instinctive prescience should have led individuals, that stand as small, isolated outcroppings from the stream of germ-plasm, to such refined cultivation is indeed quite remarkable!

All this effort centers about some source of energy in which the *Atta* is interested. All life's prescience is directed toward some source of energy. In the case of *Atta*, it is the energy that may be obtained by eating the fruit of a fungus that grows upon the leaf pulp that the *Mediums* prepare. If a spore of black mold fall upon a piece of moist bread a filament will develop from the germinating spore. This filament will throw out enzymes that will dissolve some of the adjacent bread. The dissolved bread will be absorbed. As the absorbed bread is assimilated the filament grows. In time a greatly tangled mass of filaments will permeate the entire piece of bread. Sooner or later these filaments or hyphae will put out upright unbranched hyphae upon which spore-cases will be formed. The plant is now said to be fruiting. Each spore-case contains many spores that are propagation cells capable of inoculating other pieces of bread. This plant is one of the molds.

It appears that it is one of the molds that the *Attas* have taken to cultivating. In their cultivation of this fungus, the ants have not allowed it to fruit. Under the care of the ants (perhaps only the *Minims*) this fungus, however, produces an artificial fruit. When upright hyphae appear on the leaf pulp the ends branch and the termini of the branches become dilated and abstricted or cut off. Because of this habit of growth, each upright hypha bears a tufted mass of nodules which seen under a hand lens suggest the appearance of kohlrabi heads. This fruit, which seems to have arisen through "the influence of cultivation and selection on the part of the ants,"[1] has been called, therefore, a "kohlrabi cluster." These "kohlrabi clusters" are the food upon which all members of the *Atta* colony feed.

Thus, just as the prescient effort of man has resulted in highly specialized food-plants and animals, through his cultivation and selection, so it appears that the instinctive prescience of the *Atta* has brought about a plant as artificial as any which men have developed.

There is one time in the life of the queen when she becomes directly concerned in the future food supply. This is when she is about to establish a new colony.

The virgin female, about to establish a new colony, becomes greatly excited. She leaves the parental nest accompanied by industrious *Minims* which preen her for her "marriage flight." This young queen climbs to some elevation and there repeatedly tries her wings. Eventually she flies away taking with her neither *Minims*, *Mediums*, nor *Maxims*, in time deserting even the males that have followed her. Thus, except for

[1] "Ants," W. M. Wheeler, 1910, N. Y., p. 326.

a great many sperm-cells and some hyphae taken from the parental garden, she has completely cut aloof from her home nest. She is thus left without any workers to help her establish a home for herself. Her instincts, however, are equal to the occasion. She digs beneath the soil closing her path behind her and then sets to work to make a home. Her first concern is the precious bit of fungus, that through all the unusual experiences through which she has passed since leaving her parents' home, she has carefully retained. She now lays the fungus down and supplies it with food by discharging some fecal material upon it. In the meantime she lays eggs, some of which she herself eats—eggs at present are of less value than is the fungus that is destined to supply food for great numbers later. From the eggs that are not eaten there first develop *Minims*. As soon as these appear, the queen ceases to pay any attention to the fungus. The fungus is now cared for by the *Minims*. Next the *Mediums* appear. These now leave the nest and bring back leaf-fragments. By the time the *Mediums* have appeared the queen has become a mere egg-laying organism reduced almost to the monotonous routine of a machine. The young queen shows quite generalized instincts for the brief period that extends from her taking up her "marriage flight" to the appearance of her first children. After that her functions in the colony become as clearly defined as do those of any other class.

The division of labor and differentiation of individuals, met with in the *Atta*, center about their instinctive prescience caring for a certain plant—and that plant a fungus!

Instinct in this case failed to lay hold to a basic

food source; for the fungus lacks chlorophyl (as do all fungi). Because of the absence of chlorophyl in it, the fungus cannot elaborate sugar, which is the basic food of plants. The *Atta's* effort is, thus, much like man's would be were he to take to rearing ever-increasing herds of cattle as his food supply and give no thought about increasing the acreage from which the stock-food should be taken. The *Atta* takes chances on there ever being, enough chlorophyl-bearing plants behind her fungus. Instinct, no matter how far it is developed, is inferior to intellect in that it does not see as far ahead as does intellect or reason and in that it curtails the completeness of the individual.

The *Atta*, like man, has gained a secure hold upon its future food supply. Without machinery, they, too, have made famine impossible. But this prescience has been acquired at the expense of the individual's entity and neither here nor anywhere in the animal kingdom, where instinct predominates, can we recognize a degree of knowing that could be termed even vague self-consciousness.

Moreover, instinctive effort leads more directly, more positively toward specialization than does rational effort. And specialization—other things being equal—leads to fixity of type; as Dr. Willey says: "The adoption of a specialized diet marks the culmination of a phyletic career." If this be true, the *Atta* has indeed run his radial course. It may be that man shall have realized his phyletic career, when, through chemical efforts, he shall have fallen upon some universal synthetic food that will emancipate him from the green plants. I cannot conceive, however, of man's career thus being ended. For when material

things shall have thus been guaranteed the human individual, he will find himself free to struggle for a fuller development of his personal consciousness or spirit—intellectual, unlike instinctive, evolution is leading to higher and higher realization of the conscious self. This is the direction human evolution has taken. Along this path it must continue. As this advance proceeds the struggle will become less and less one of race with race and more and more one of person with person. The discovery of a synthetic food for man may mark the dawn of some moral era wherein the struggle will not center about food but about the complete personal realization of intellectual, moral beings.

CHAPTER III

SOLITARY INSECTS LOOKING INTO THE FUTURE

The prescience of solitary insects stands in sharp contrast with that of man and the social insects in one respect.

Man as an intelligent and rational animal cannot realize his complete potentialities without association with his fellow-men. Human society thus becomes the womb within which the intelligent and rational human individual is developed. Arising out of the organization of human society is a social heritage. This heritage awaits each human individual at birth. Vast stores of information await each human child. Man is a "time binding" creature. As such he has enabled each generation to take up the quest for knowledge where the previous one had quit. This fact makes man unique.

While the social insects do not differ so much from the solitary ones as does man, yet a contrast may be drawn here also. The social insects, too, must live with their fellow creatures, if their potentialities are to be realized fully.

So conspicuous is the prescience of social animals that it might appear social organization is necessary for the attainment of a high degree of instinctive prescience. But such is not the case.

Even solitary animals, that are much more lowly organized than social insects, have blindly hit upon

many biological facts. For example, a certain thread-worm has discovered that the highly concentrated proteid substance, represented by the poison of the rattlesnake, will serve as its proper food. Because of this the poison sack of the rattlesnake has become the peculiar habitat of this little nematode. Moreover, this worm has selected the task of maintaining itself, as a species, from generation to generation in this obscure nook of the world.

Again a less complex animal than the thread-worm, the liver-fluke, has succeeded, in its racial prescience, in keeping step as it were, with two radically different and diverging lines of evolution, in order that it may endure as a species. This lowly organized flat-worm has followed, in its adaptability, not the evolution of a single host but that of a warm-blooded terrestial animal—the sheep, and that of a cold-blooded aquatic animal—a snail. The remarkable details of the fluke's life history are well known. Enough has been given to indicate that neither complex social organization nor complex anatomy may be necessary for the display of a high degree of prescience on the part of an animal.

It is not surprising therefore, to find that solitary insects, in their prescience, may outstrip animals that may show more aptness for intelligent conduct. In the following example, blackbirds were seen to display a greater power of perceptual inference than could have been shown by a bumble-bee. One May day after a thunder storm, my father called my attention to some blackbirds that were displaying intelligent conduct. These unusual blackbirds had observed that a robin's tapping on the ground may mean that an earthworm

could be found. So they strutted about dashing at a robin only after it had pounded the turf. In many cases the blackbird would get there just in time for the earthworm that the robin's tapping had caused to come to the surface. They had not learned their lesson well; for in case one chased the robin too early, it did not wait at the spot until the worm appeared at the surface. And yet these birds were showing a form of conduct, arising out of their own experience, such as one would not expect a bumble-bee to carry out.

But when it comes to making a nest, the queen bumble-bee, *acting alone* shows a more marked prescience than does a bird when it constructs its nest.

Bombus terrestris at this time seeks a suitable cavity in the ground. When this has been found, she lines it with pieces of grass or moss. Next she collects pollen and mixes this with nectar to form a pellet of paste. Upon this she builds a cylindrical waxen cell within which she deposits her first lot "of eggs. The queen now sits on her eggs day and night to keep them warm" (or to protect them), "only leaving them to collect food when necessary. In order to maintain animation and heat through the night and in bad weather when food cannot be obtained, it is necessary for her to lay in a store of honey. She therefore sets to work to construct a large waxen pot to hold the honey." [1] Thus the queen bumble-bee at nest making time behaves much as birds do, in that she collects material with which to make her nest. But she goes beyond the bird, in her prescience, when she makes a vessel at the door of her nest and fills it with nectar

[1] "Social Life of the Insects," Wm. Wheeler, *Scientific Monthly.*, Sept., 1922, Vol. 15, p. 251.

so that she will not be compelled to leave the nest too long when food is scarce.

The prescience of some solitary insects has not only surpassed that of birds, but it has also antedated, in some instances, that of man.

Man has only recently been able to arrest bacterial decay effectively. Honey bees, throughout the period over which human recorded history has extended, have been indefinitely rendering their honey safe from bacterial fermentation. Only in 1880 did man learn how to control such decay. The discoveries of Pasteur at about that time represent one of the great outstanding steps that the human race has taken. Centuries—ages before human progress took this step, honey bees must have been doing as they now do. These insects protect their honey from bacterial decay by injecting a droplet of poison from the sting within each honey-cell from time to time. This is why honey will not sour within the hive. Now bees have been known to man for thousands of years. Hence throughout all these centuries and of course long prior to this, bees, in their instinctive prescience, have stumbled upon the biological fact of the control of bacterial decay.

Certain solitary wasps, too, have been working successfully with this biological fact.

The control of bacteria is involved in the *Sphex* moth's conduct in preparing food for her future progeny. The female *Sphex* carries out a sustained series of operations in preparing food for the larva that will develop from the egg, the presence of which in her body may be the driving force behind all her operations. She first selects a suitable place in the ground. Next

she secures water and with the aid of this water and her mandibles she excavates a breeding tunnel within the sandy soil. After the excavation has been completed, she takes the precaution of closing it with small pebbles and of fixing in her memory the tunnel's exact location. After this has been done, she flies off to find a larva of the sphinx moth. The first step in her prescient conduct, therefore, was to make a tunnel in which to house a larva that she is now seeking. The insect's prescience becomes further evident when a sphinx larva has been found. For she stings this larva until it is motionless. The larva may or may not be killed. In either case it is rendered passive. But the important feature of the wasp's attack is that the sphinx larva is rendered immune to the attacks of bacteria of decay by the posion injected into its body when it was stung. The quieted and immunized larva is laboriously dragged back into the excavation by the wasp. An egg is now deposited upon the dead or dormant larva. Then the parent wasp carefully closes and conceals the breeding chamber with pebbles and sticks which she piles over the burrow's mouth. In one species, *Sphex urnarius*, the wasp selects a suitable pebble with which to tamp soil down into the mouth of the breeding chamber. (Fig.1.)

Fig. 1.—"*Sphex urnarius* using a selected pebble to pound down earth on burrow." (From Wm. M. Wheeler after G. W. and E. G. Peckham.)

After the exit has thus been closed and concealed, the prescience of the mother wasp ends and her instinctive interest no longer follows the potential child represented in the egg. But her prescience has gone far enough, for it has provided sufficient and proper food for the larva that will develop from the egg.

The prescience of another solitary insect has successfully manipulated another biological fact that man must have put into practice much later.

Indeed this fact was so recently known to man that Darwin was able to make a conspicuous use of it when he pointed out that England is indebted to her spinsters for her soldier boys. At first sight one is led to infer from this that England's army enlistments were made through lads entering the army after being jilted by the fair maidens who remain spinsters. But this is not what Darwin had in mind. He indicated that spinsters keep cats. Cats kill field-mice. Field-mice kill bumble-bees. So with the field-mice killed off, bumble-bees flourish. These bees alone can pollinate the red clover. Hence where there are many bumble-bees there will be a larger crop of clover-seed. A large crop of clover-seed makes possible a large crop of clover. Upon this crop many beef cattle can be fed. And a large supply of beef makes possible a well fed English nation, from which England draws recruits for her army. Hence she depends upon her spinsters for her "Tommy Atkinses."

This was said in a playful mood to illustrate the interrelation between living forms, but in a practical manner men have learned to deal with cross-pollination by way of securing a future supply of some particular food.

At certain seasons Arabs along the banks of the Tigris River may be seen at work transferring pollen from flower to flower of their date palms, "for in this country palms have to depend upon human energy" for pollination.

When the Smyrna fig was introduced into California, the trees grew and flourished but produced no fruit. It was then realized that an important insect had been left behind in Asia Minor. These were the insects that carry the pollen from one flower to another. The next step in man's prescience in this matter was now taken and some of these insects were brought into California in 1900. Since that time the production of the Smyrna fig has become an important Californian industry.

Ages before men, in their rational prescience, had arrived at facts such as the above, a certain solitary insect had learned, in her instinctive prescience, how to cross-pollinate a plant.

This insect is known as *Pronuba yuccasella.* As its specific name indicates, this small moth is associated with the plant, *Yucca* or "Spanish bayonet."

The flower of *Yucca* has a perianth of six white units. Within this perianth are six relatively short stamens that produce a sticky pollen. The pistil is compound. In its base are six parallel rows of ovules which will become seeds, if pollen from another flower be applied to the stigmatic surface of the pistil. The stigmatic surface is found lining the lumen of the tubular outer end of the pistil.

When a female *Pronuba* comes to a *Yucca* flower, she first gathers up a pellet of the sticky pollen and places it against the underside of her head. She now

flies to another flower and settles her body between the bases of two of the stamens of this flower. Then she thrusts her ovipositor through the wall of the pistil and deposits one of her eggs into a row of ovules. Next she ascends the pistil and rubs some of the pollen, that she had collected from another flower, into the stigmatic tube (Fig. 2). She now goes down between the bases of two other stamens and deposits an egg into the second row of ovules, after which she a second time applies the pollen to the proper surface of the stigma's lumen. This is kept up until she has laid an egg into each one of the six rows of ovules and has six times applied pollen to the stigma of the pistil.

Her eggs in time will incubate and from each a larva will emerge. By the time the larva has emerged the seeds of the *Yucca* have developed considerably. These seeds form the sole diet of the larva. Thus in collecting pollen from one flower and using it upon another flower after each time laying an egg into the ovary of the second flower, the *Yucca* moth has provided food for her young as they will emerge from their respective eggs.

Whatever the factors have been that brought about this remarkable prescience on the part of *Pronuba yuccasella*, they have wrought well. For, in the first place, the moth has not followed the line of less effort to gather pollen from the flower that is chosen for egg deposition, but two flowers are involved on all occasions. Secondly no chain of the plant's ovules are missed, nor are there too many eggs deposited. There being six rows of ovules, six eggs are deposited—one to each line of ovules. There is in these phenomena a degree of restraint exercised on the part of the moth

FIG. 2.—"Flowers of *Yucca* visited by the moth *Pronuba*. The work of the moth is suggested by its position in the several flowers. In the first (lowest) flower, the moth is gathering pollen; in the second, she is pollinating the stigma; in the third, she is in the position of rest during the day; in the fourth, in the position of rest when disturbed; in the fifth, ovipositing." (From Bergen and Caldwell's "Practical Botany.")

that must not be overlooked. Each line of ovules when once developed into seeds will supply more food than one *Pronuba* larva needs. Despite this fact but one egg is laid to a row of ovules. In this way some seeds are left uninjured and thus the *Yucca* too may be perpetuated. Egg laying without restraint would soon put an end to *Yucca* and thus, in turn exterminate *Pronuba yuccasella*.

Again, this instinct has become so fixed and habitual that the *Yucca* depends entirely upon this insect for cross-pollination. The *Yucca* would die out within a generation, were these moths as a whole to disappear.

It taxes one's imagination to consider that natural selection has so guided synchronously two lines of evolution—one that of the evolving *Yucca* and the other that of the evolving *Pronuba*—that, through such selection this high degree of prescience has been attained by *Pronuba* in caring for the offspring which she may never see.

But the effort to apply the theory of natural selection to explain the prescience of solitary insects with reference to their progeny, becomes more difficult when we see that others have evolved with reference to, not the method of plant propagation, but to that of animal propagation.

In the summer of 1904 I found scores of large ichneumon flies at work drilling deep into the wood of some catalpa trees that stood in front of Princeton Inn. These were female *Thalessa lunators*. Each ichneumon was drilling into the tree at a point over the excavation that was being made by a grub of a "horntail" insect. When the excavation of the "horntail" is reached, the ichneumon lays an egg into it. This

egg develops into a small larva, which overtakes and feeds upon the "horntail."

In this case two lines of evolution must have run synchronously in such manner that the prescience of the ichneumon was brought about. Surely if natural selection had been the guide that led to this, it has wrought meticulously; like the mills of the gods, it has "ground exceedingly fine!"

Though I feel that any theory of creation is sorely taxed to explain the origin of these remarkable instincts, I do not wish to leave the impression of giving credit to bees in sterilizing honey, to *Sphex* in immunizing larvae against bacterial decay, to plants in laying traps for bees, to *Pronuba* in cross-pollinating *Yucca* flowers, and to ichneumon flies in drilling for *Tubex* larvae.

On the contrary, a conspicuous contrast may be drawn between the instinctive conduct of these organisms and the intelligent and rational conduct of man. The insects have made little of the facts about which their instinctive prescience plays. For example, no great progress is being made by ants that can grow pure cultures of fungi. Ants that were fossilized in amber fifty million years ago had "developed all their various castes just as we see them to-day, their larvae and pupae were the same, they attended plant-lice, kept guest beetles in their nests and had parasitic mites attached to their legs in the very same peculiar positions as in our living species."[1]

In contrast with all this permanency of form and conduct, man's conduct appears highly plastic. He

[1] "Social Life among the Insects," Wm. Wheeler, *Scientific Monthly*, Vol. XIV., 1922.

rears to-day no longer the same varieties of plants and animals that were cared for five thousand years ago. Parasites that troubled him last century are now kept in check. Diseases, like yellow-fever, malarial fever, typhoid fever, small pox and hook-worm infection, no longer determine whether or not some great engineering project may be undertaken. One hundred years ago the Panama Canal, for example, could not have been built, even if man's mechanical skill had been as it was at the time the Canal was built. To-day the uncontrolled *Pediculus humanus* is responsible for the havoc typhus fever plays in certain parts of the world. But though lice have been clinging to the legs of ants for fifty millions of years, it is hardly to be expected that fifty million years hence the "coutie" and typhus will be troubling man. Intelligent, rational man is too plastic to suffer such pests so long.

Insects, too, may have been plastic at one time. For despite the plasticity and resourcefulness of humanity, it has seldom duplicated any invention or discovery. Gun powder may have been independently invented twice. It is also held that the principle of the boomerang has been discovered twice by man. Not many such examples of duplication can be found in the history of human effort. Examples of duplication can be encountered in the insect world that in their frequency stand in sharp contrast with the few to be found in human history. For instance "social organization has arisen *de nova* on at least twenty-four different occasions in nearly as many natural families or sub-families belonging to five different orders of insects."[1]

[1] "Social Life Among the Insects," Wm. Wheeler, *Scientific Monthly*., Vol. XIV, 1922.

The period of plasticity has been passed by the social and solitary insects and we see their prescience displayed by fixed reflex and instinctive action. The conduct of man on the other hand is plastic and guided by a self-consciousness.

But we must not let the comparison that has been drawn between man, social and solitary insects conceal the fact that all of this conduct is characterized by its prescience.

This, the chief characteristic of organic action, is overlooked by those who would explain an animal's conduct in terms of its complexity of structure. These men call attention to the fact that an insect's central nervous system or that of man is composed of millions and millions of neural entities capable of being arranged in various groups and series of groups so as to determine a certain structure or conduct. And they draw the analogy that just as the twenty-six letters of the alphabet may be so arranged in groups or series of groups as to give results ranging in complexity and value from the child's stammering "C-A-T, cat, B-A-T, bat", etc., to a great epic, so these neural entities may be arranged in groups and series of groups giving results ranging from the simplest reflex to the most exhaustive reasoning. I must indicate, however, this analogy breaks down when we keep in mind the prescience that is characteristic of life. The arranging of material entities, be they letters of the alphabet or neurones, results only in a spatial series, that may represent a record of the past but does not explain how prescience enters into conduct.

Man, social insects, and solitary insects are always faced toward the future. The prescience of the insects

is directed primarily toward the security and propagation of the species; whereas, man's prescience is directed primarily toward the fullest realization of his self-conscious personality.

CHAPTER IV

TYPES OF SIMPLE MULTICELLULAR ANIMALS

So much has been said about the idea first advanced by Schleiden and Schwann concerning the bodies of men and other ordinary animals being made up of many cells, that to-day the average layman is acquainted with the fact. The average man knows, for example, that a dog's body is composed of many such units and that these units or cells may be compared to the unit of structure in a brick wall. He has been told further that these organic units are composed of protoplasm just as bricks are made of clay. And further, just as bricks are assembled to form walls so the cells of an animal's body are differentiated and segregated to form tissues. The tissues in turn are segregated in various ways to form the different organs of a multicellular animal's body. So much have tissues and organs been emphasized, that it becomes very difficult for a layman to think of an animal that lacks, for example, brain, heart, and other organs common to the higher animals. In this he is but retaining the conception that some biologists of the seventeenth and early eighteenth century held. These men described hearts, blood-vessels, brains, and the like as being in animals whose bodies consisted of but one cell. This was a gross blunder of these early biologists, for there are numerous multicellular animals which do not have many of the organs that are conspicuous features of the higher animals.

It matters not how simple may be the structure of an animal there are always certain physiological demands that must be provided for. For example, the animal must have water, food, heat, etc. The fundamental physiological demand for food plays about the two facts of energy and matter in such manner as to retard the drift of events presented in inanimate nature.

In the inanimate world two laws of thermo-dynamics hold sway. The first is called the law of conservation of energy; the second may be designated the law of degradation of energy. In the first law men recognize the fact that energy may neither be created nor destoyed. According to this second law "the substance of the earth is constantly tending to arrive at a condition of greatest entrophy, meaning 'rundownness.'"[1] Likewise all energy in the universe is tending to arrive at a state of equilibrium. The sun, though now much hotter than its related planets, is giving off heat to these satelites and will in time, unless its energy be renewed, have exactly the same temperature as its planets. This process is happening throughout the universe. When this degradation of energy shall have run its course, there will be no available energy with which organisms could carry on their metabolism. It is against this second law of thermo-dynamics that living things are constantly working. Indeed the effort to check temporarily this process of energy degradation becomes fundamental to living beings. It is one of the fundamental attributes of life. The plant reveals this attribute in its photosynthesis and the synthetic pro-

[1] R. W. Thatcher, *Journal Industrial and Engineering Chemistry*, 1922, Vol. 14.

duction of proteins. The basic function of plants is, therefore, photosynthesis. The animal takes over the synthetic compounds of plants and in its working against the law of degradation of energy digests and absorbs these compounds and stores them in the form of animal protoplasm, proteins, glycogen, fats, etc. The basic demand of the animal is, therefore, alimentation. Alimentation is a double process. It involves the digestion of food and the absorption of digested food. Hence the simplest multicellular animal must first be at least an alimentary organism. Next it must have some means of going after its food or bringing its food to it; for the food of animals, unlike that of plants, is not supplied them on all sides. The plant's proper parts are bathed with the carbon dioxide, sunlight, and moisture that they need for their nutrition. The little lad who upon tasting his first ice-cream remarked, "My, I wish the whole world were ice-cream!" was expressing a wish beneath the dignity of an animal. Were the animal to realize its food on all sides, listlessness, a state of non-motility almost if not quite equal to that of the plants would result. So to remain a typical, active animal, a simple multicellular animal must have some means of laying hold of its food and going after it, if necessity demands.

Again a multicellular animal of the simplest type must have some means of recognizing food and non-food and of exercising a regulatory and inhibitory control over itself. Without the sense of food recognition it would be in danger of starving in the presence of food and without the power of regulatory and inhibitory control over itself it would be in danger of dying a glutton's death.

Finally a multicellular animal, no matter how simple, must provide a method of propagation.

It is possible that all these conditions were met, in the past, by a monoblastic type of animal. An animal of this type would be one whose rounded body has all its cells arranged at the periphery to form a single layer. The body wall of a monoblastic animal would, therefore, be one cell thick. There is no such animal extant. But in *Volvox* we have a very loosely organized monoblastic plant. *Volvox*, though a plant, moves about and in many respects resembles an animal. The existence of this animal-like monoblastic plant helps one to picture what monoblastic animals must have been like and strengthens the inference that animals of this type must have existed at one time. This inference is further supported by the fact that all multicellular animals, in their early embryological development, pass through a monoblastic stage. This embryonic stage is called the blastula. Figure 3 shows a section taken through the vertical axis of a blastula of *Amphioxus*. If such a monoblastic multicellular animal had existed in the past it must have met in some manner the conditions of animal life outlined above.

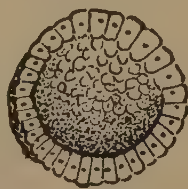

FIG. 3.—A section of a blastula of a little fish-like animal, *Amphioxus*. (From Zeigler's models.)

One of the simplest diploblastic animals to be found to-day is called *Hydra*. This little polyp is widely distributed throughout the fresh waters of the world.

The body-proper of all polyps is more or less a cylindrical sac (Fig. 4). In the case of *Hydra*, the body-proper is a small truncated cone with its sides so steep

as to cause the contour to become nearly cylindrical. The truncated end of this conical sac is closed. The

Fig. 4.—The fresh-water polyp, *Hydra*. *St*, stinging threads (nematocysts); *T*, tentacles; *P*, peristome.

animal is usually found with this basal end adhering to the surface of some submerged object. The free end, which represents the base of the cone, bears a

mouth that is surrounded by a circular, conical lip (Fig. 4, *P*). This lip is called the peristome. From about the base of the peristome, a zone of tentacles arises. These are organs of prehension. They are also to a certain extent sensory, and defensive organs; for though the body-proper can respond to stimuli and can defend itself as do the tentacles, yet the latter are more sensitive and more effective as defensive structures.

When the animal is seeking for food it sways its greatly elongated tentacles to and fro through the water. In case a small animal is encountered by one of these tentacles, the prey is stung by the "nettles," "stinging threads," or nematocysts (Fig. 5). Another type of nematocyst anchors the paralyzed prey to the tentacle (Fig. 6). The food is then dragged toward

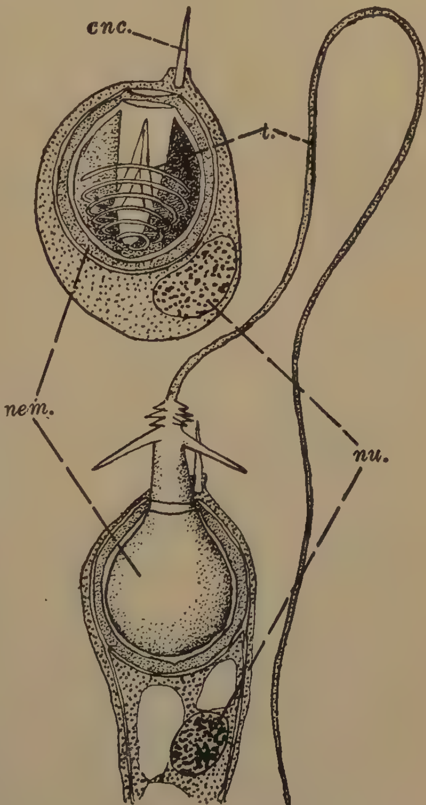

FIG. 5.—Above, an undischarged cnidoblast of *Hydra;* below, a cnidoblast in the act of discharging its nematocyst: *nem*, nematocyst; *cnc*, cnidocil; *t*, penetrating thread; *nu*, nucleus of cnidoblast. (From Dahlgren and Kepner after Schneider.)

the mouth, where the peristome lays hold of it and carries it down into the cavity of the body-proper. If the prey be large, much work will be displayed by the peristome in forcing the large mass of food into the cavity of the body-proper. Sometimes an object, by weight one, two, three, or more times the size of the *Hydra*, will be ingested or swallowed. When such a large meal has been ingested, the body-proper is greatly distended and conforms, in a general way, to the contour of the ingested food-mass.

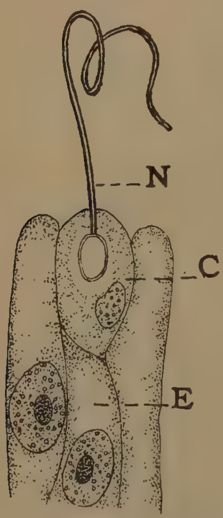

Fig. 6.—Cnidoblast with a discharged "grappling" stinging thread (nematocyst). *C*, cnidoblast or cell that had elaborated the grappling nematocyst, *N*; *E*, end of epitheliomuscular cell of ectoderm. ×1000.

In order to understand how this mass of food is appropriated by the *Hydra*, it will be necessary to examine under the microscope a slice taken lengthwise through the axis of *Hydra*. A similar slice through the axis of a football would show two layers. The inner layer of this section of football would be relatively thin and composed of rubber; while the outer layer of the section would be relatively thick and composed of leather. A slice through the axis of *Hydra*, likewise, shows two layers. Each of these layers is a multi-cellular tissue. The inner one is the thicker. This tissue has two types of cells: (1), secreting cells and (2), absorbing cells (Fig. 7, *B*, and *a*). When a large mass of food is taken into the enteric cavity, digestive fluids, containing enzymes, are thrown upon it. The food will be in part digested by the enzymes and the

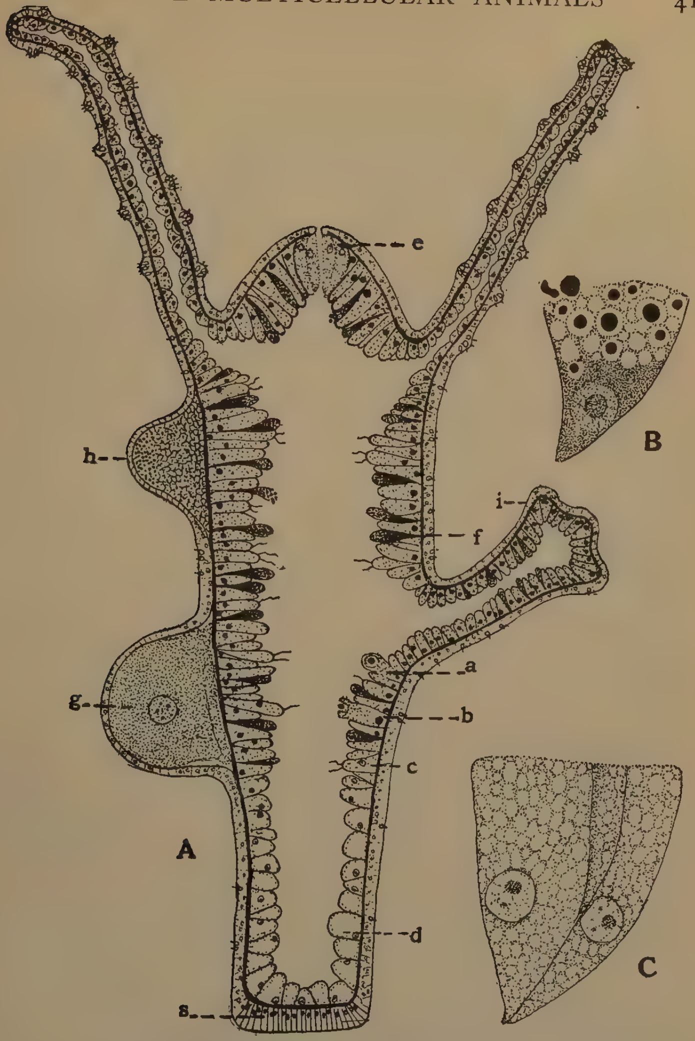

FIG. 7.—A, diagram showing longitudinal section of *Hydra; e,* and *f* show distribution of two types of secreting cells of endoderm; *a, b, c,* and *d* show phases of food ingestion by epitheliomuscular cells of endoderm; *b* is about to surround a particle of food, *a* has surrounded one; *i,* ectoderm of tentacle; *h,* testis; *g,* ovum, within ovary; *s,* adhesive cells at base. *B,* a general secreting cell of endoderm. ×1500. *C,* two of the highly specialized endodermal cells to be found about mouth. ×1500. (From Kepner and Hopkins).

dissolved food or chyle will then be taken up by the absorbing cells. The absorbing cells not only take up the chyle, but they also surround and take within their bodies small fragments of food. When such a minute mass is thus taken within the cell it is therein digested. The indigestible parts of these food particles are thrown out into the enteric cavity. No food can be handled by the cells of the outer tissue. The inner tissue (endoderm) is thus assigned to the task of getting food not only for itself but for the outer tissue also.

Thus food is obtained and the basic demand of animal existence is met and the polyp grows.

The endoderm or inner tissue takes part in another function that is more conspicuous in animals than in plants—movement. At the base of each absorbing cell the protoplasm is differentiated to form contractile fibrils. These fibrils are technically called myonemes. The cells having these contractile elements of protoplasm are, therefore, called epithelio-muscular cells. The myonemes of these endodermal epithelio-muscular cells are disposed at right angles to the axis of the *Hydra's* body. They form circular bands of contractile fibers within the animal's body wall. When they contract they bring pressure to bear upon the body at right angles to its axis as do one's fingers bring pressure to bear upon a piece of wax when the hand is tightly closed about it. In the latter case the wax elongates, so likewise when the muscle fibers of the endoderm contract the body of the *Hydra* slowly elongates. If there were no muscles playing antagonistically to these circular muscles of the endoderm, the *Hydra* could not readily contract. As a matter of fact, the *Hydra* can very quickly contract.

This rapid contraction is due to the functioning of some myonemes that are to be found in the bases of the ectodermal epithelio-muscular cells. The muscular fibers of these cells of the outer tissue run more or less parallel to the axis of *Hydra's* body. They are associated with a nerve-net which makes the ectoderm a neuro-muscular tissue. The endoderm, on the other hand, has no nerve-net system associated with it. The latter, therefore, functions much less rapidly than does the ectoderm, which is a neuro-muscular complex.

The ectoderm, however, is more than a neuro-muscular tissue. Filling the interstices of the epithelio-muscular cells are groups of small cells that are much like the meristematic cells of plant tissues or the undifferentiated cells of an embryo, in that they have not yet become fixed in type. It would be futile to place an embryonic retina beneath the skin of an adult frog's side with the expectation that the superimposed epidermis would become transparent and take on the characteristics of a cornea. And yet when such a transplantation of the optic vesicle is made beneath the skin of an embryonic frog's side before the epidermis had become fully differentiated, these cells form a cornea-like transparent region. So here the interstitial cells have not as yet become fixed. They retain their generalized type and are potentially able to develop into ectodermal epithelio-muscular cells if need be. The demand for other types of cells is great. So we find these cells at times becoming cnidoblasts. Cnidoblasts are cells that elaborate the "nettles," "stinging threads," or nematocysts to which reference has already been made. An interstitial cell in becoming a cnidoblast first enlarges. Next a vacuole is formed

into which an organic substance is thrown (Fig. 8). This organic material is now molded into a nematocyst. The nematocyst is an oval sac containing a poisonous liquid that bathes a very long, slender introvert (Fig. 5). When the receptor of the cell is properly stimulated this introvert is everted with such high velocity that it may perforate the cuticle and enter the tissue of a relatively large worm. Through this wound the poison of the nematocyst enters the body of the animal and partially paralyzes it. With the discharge of the nematocyst the cnidoblast, that elaborated the nematocyst, is lost. Other cnidoblasts must arise from interstitial cells to take the place of those lost each time nematocysts are discharged.

Fig. 8.—Three young cnidoblasts lying within bay formed by the body of an epitheliomuscular cell of *Hydra*. Organic material, *m*, that will be shaped into a cnidoblast is to be seen within a vacuole of each cnidoblast. Drawing made from slide of Dr. F. J. Wright, series 6, No. 1, 41.2—81.5.

So the diploblastic *Hydra* is able to eat and grow, move from place to place, and defend itself through a physiological division of labor resulting in its cells being first differentiated into ectoderm and endoderm and then having the cells of each of these tissues further differentiated. The individual *Hydra* is thus able to maintain itself. The rôle of the living individual, however, does not end with self-preservation. Provision must be made for propagation.

There are two forms of propagation to be encountered in *Hydra:* (1) asexual and (2) sexual.

In the asexual method both tissues are involved.

An outgrowth of the outer body wall appears; as this advances a small sac, with ectoderm and endoderm forming its wall and with its lumen communicating with that of the parent, is formed. This diploblastic sac is called the bud. The growth of the bud continues and eventually the free end of the bud develops a mouth. About the base of the lip of the developing mouth a zone of secondary buds appears (Fig. 7, *i*). The secondary buds are the rudiments of the tentacles. While this process has been advancing, food has been supplied by the parent. Eventually the bud has well developed tentacles after which its base becomes constricted and it drops from the parent as a young *Hydra*.

The interstitial cells are involved in sexual propagation. Under certain conditions some of these become sex-cells or gametes. The gametes of *Hydra* are of two kinds: male and female. The male gametes or spermatozoa are very small and highly motile. The female gametes or ova are very large and passive.

Certain interstitial cells in the oral third of the body divide repeatedly and form great numbers of very small cells (Fig. 7, *h*). These small cells develop flagella and are known as spermatozoa. They are retained within the body of a thin-walled testis and finally released into the water.

Of a certain group of interstitial cells of the middle third of *Hydra's* body, one feeds upon its fellows and in this way grows. It attains great size and is retained within a thin-walled ectodermal sac (Fig. 7, *g*). This is the ovum. Unlike the male gamete, it is not released into the water.

In time a sperm cell enters the sac or ovary that houses the ovum and penetrates the cytoplasm of the

ovum. The nucleus of this sperm cell unites with that of the egg and a fertilized egg or zygote results. This zygote develops into a ciliated diploblastic larva within the ovarian sac. It is then released. The ciliated larva swims about until a suitable place is found; when it fixes itself to some submerged object and develops into a polyp.

It is thus seen that in *Hydra* we have an animal that is little more than a very simple alimentary sac and yet it can not only eat and grow, but move from place to place, realize when it is in favorable or unfavorable conditions, and propagate itself in two ways. It is prepared even to meet the agression of its neighboring *Hydra* by giving combat. October seventeenth, 1914, two *Hydras* found themselves in close propinquity and began a battle as Mr. Harryman was observing them under a microscope in my laboratory. As their respective tentacles approached they began an exchange of shots with their barbed nematocysts. This was kept up for some time. Then, as though their ammunition had given out, they took hold of each other with their "grappling" nematocysts and repeatedly tore off ends of each others tentacles. This battle was continued while Dr. Taliaferro and five of Mr. Harryman's classmates took turns at observing the battle. The battle suggested the fight of the Kilkenny Cats that fought and fought till only their nails and tails were left. All this self-assertiveness was carried on despite the fact that *Hydras* lack highly developed organs of special sense, an efficient circulatory medium, etc. It becomes evident therefore that such organs are not essential for mere multicellular animal organization.

In *Microstoma* some of the things not made possible by diploblastic organization have been realized.

Hydra differs from *Microstoma* in not being triploblastic and in not being bilaterally symmetrical. *Hydra's* radial symmetry does not lend itself well to the development of organs of special sense and to the formation of a circulatory system. Radial symmetry is an extravagant symmetry when it comes to using organs of special sense. This extravagance may be illustrated by conceiving of a baseball provided with an eye and a mechanism behind it whereby it could dodge the batsman's bat. One eye would be of very little use to the rotating radially symmetrical baseball. There would have to be frequent eyes each disposed at the end of a radius, if at all times the bat could be observed and thus avoided. Two eyes would not serve such a living baseball. So likewise radially symmetrical animals cannot get along with a pair of each kind of organ of special sense. The jellyfish which are radially symmetrical, diploblastic animals have organs of special sense at the ends of many of their radiuses. Moreover, their circulatory vessels are but canals that represent vestiges of a cavity that is the homologue of *Hydra's* enteric cavity. The jellyfish represent the greatest attainments that radial symmetry and diploblastic organization afford.

The next step above the *Hydra* and the jellyfish in multicellular organization is aptly shown in animals like *Stenostoma* and *Microstoma*. In these little Rhabdocoeles a definite bilateral symmetry has been established and a third tissue has appeared which lies between the ectoderm and the endoderm. This third tissue is designated the mesoderm.

The presence of a third tissue makes possible the elaboration of a central nervous system, a renal organ

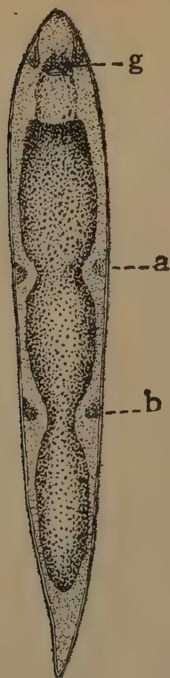

FIG. 9.—Dorsal aspect of *Stenostoma*. *g*, dorsal ganglia, immediately behind which is to be seen the mouth as a transversely disposed slit; *a* and *b*, regions in which new organs are being formed in preparation for the animal's propagation by fission. (From Kepner and Helvestine.)

FIG. 10.—Lateral aspect of a sexually mature *Microstoma*. *G*, left dorsal ganglion; *C P*, left ciliated pit; *M*, mouth; *P*, pharynx; *DN*, left dorsal nerve; *V*, left ventral nerve; *O*, ovary; *Vg*, vagina; *E*, enteron ("stomach"). (From Kepner and Taliaferro.)

(urinary organ), reproductive organs, and a circulatory medium.

The central nervous system is represented by a pair of ganglia that lie anterior to the mouth within the mesoderm (Fig. 9, *g*), a pair of ventral nerve tracts and a pair of smaller dorsal nerve tracts (Fig. 10, *DN*). This central nervous system is associated with a nerve-plexus that lies beneath the epidermis and with a set of longitudinal and circular muscles which also lie beneath the epidermis. The only clearly defined organs of special sense that are present in *Microstoma* are a pair of ciliated pits (Fig. 10, *C P*). These are gustatory-olfactory organs and enable the animal to test the quality of water through which it moves, and to locate food.

The renal system in *Stenostoma* is but a single tubule that receives many branches (Fig. 11, *K*). The termini of the branches bear peculiar "kidney" or renal cells known as "flame-cells" or protonephrostomes.

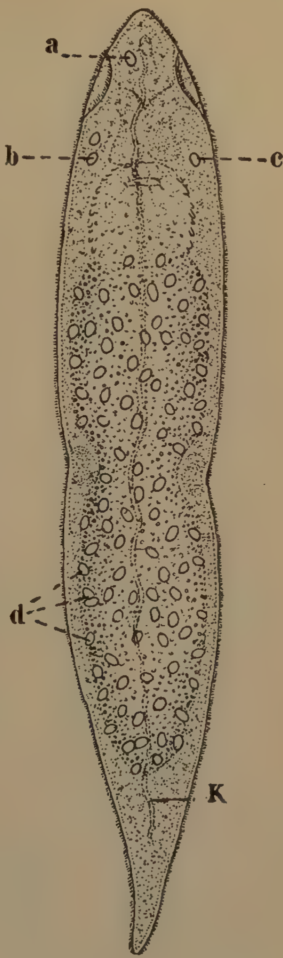

Fig. 11.—Dorsal aspect of *Stenostoma leucops*, infected with protozoön parasites that were clinging to the outer surface of the enteron ("stomach"), *d*; *b* and *c*, parasites that had travelled from wall of enteron to lie one on each side near the "brain"; *a*, a parasite that had traveled well anterior to the bi-lobed "brain;" *k*, renal tubule. ×500. (From Kepner and Carroll.)

Both *Stenostoma* and *Microstoma* are hermaphroditic. They are, however, protandrous. That is, the male reproductive system develops first and later the female reproductive system appears while the male system atrophies. It thus happens that for a time a *Microstoma* may be a male individual going about slashing with its chitonous lance or penis its more precocious neighbors, that are for the time being females, and injecting sperm-cells into the wounds it makes. Later this male individual loses its lance-like penis and its aggressiveness and develops, in place of its lost male reproductive system, a female reproductive system. It, in turn, is now wounded by the lance-like penis of its less precocious fellow creature and thus receives into the interstitial spaces of its mesoderm sperm-cells from a male specimen. After the *Microstoma* has spent a brief period laying eggs, it reverts to an asexual animal.

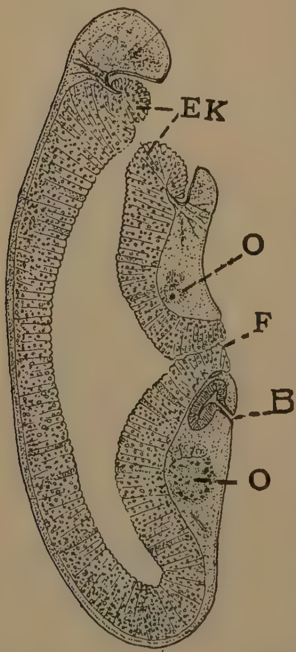

FIG. 12.—Longitudinal vertical (sagittal) section of *Microstoma* in process of dividing. *EK*, endoderm; *F*, rupture of ventral body-wall; *O* and *O*, ovaries. *B*, new mouth and pharynx arising. (From Kepner and Helvestine.)

Throughout the greater part of the year, *Microstoma* is an asexual animal. As an asexual creature it frequently propagates by division. This fission, however, is not a matter of mere constriction. Certain

organs must be differentiated before the parent may be constricted. On the ventral side of the parent midway between the ends of the body an ingrowth of ectoderm takes place. This ingrowth becomes differentiated. Certain mesenchymal cells crowd about

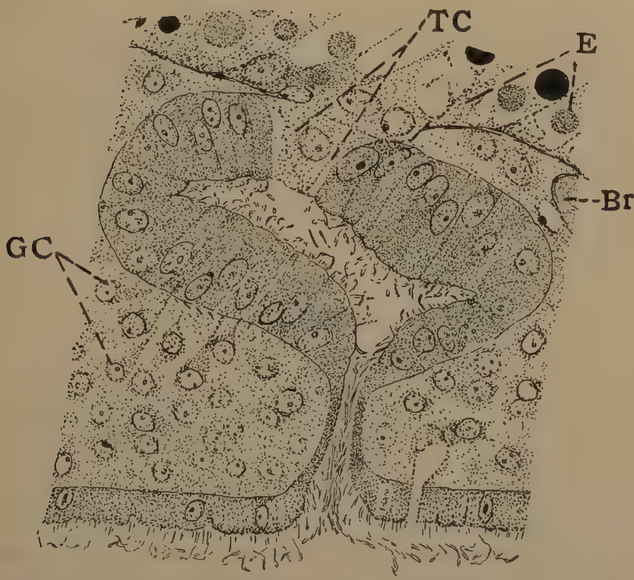

FIG. 13.—Region *B* of Figure 12 seen under greater magnification. The ciliated outer tissue at bottom of figure has been turned in to form a sac. The cells of this in-turned or invaginated region have greatly enlarged and are becoming differentiated. One of these becomes the transitional cell, *TC;* others elongate and go out into the mesoderm to become gland cells, *GC*. *E*, endoderm; *Br*, "brain." ×1500. (From Kepner and Helvestine.)

this ectodermal sac and form a muscular coat about it. From this ectodermal sac, with its muscular coat, a second mouth and pharynx is formed (Fig. 12, *B*). Figures 13 and 14 show phases in the development of a pharynx from the invaginated region of the ectoderm. While this is going on, ganglia and ciliated pits are

being developed in this mid-region of the parent's body. In time a constriction about the mid-girth of the parent appears and it becomes evident that the parent is about to break into two individuals, which

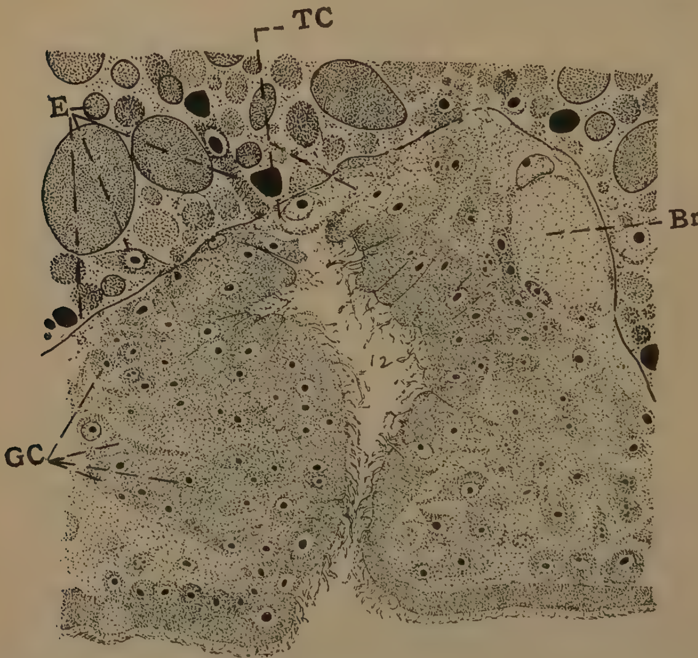

FIG. 14.—A more advanced stage in the development of the second pharynx in a rhabdocœle, like *Microstoma*. The development of the gland cells, *GC*, much more advanced here than in Figure 13. The pharynx, as a whole, has more nearly assumed the contour of the adult organ and a connection between the endoderm and the developing pharynx is about to be established at *TC*. *Br*, "brain"; *E*, endoderm. ×1500. (From Kepner and Helvestine.)

will soon be living independently as the young children of the *Microstoma*. Sometimes three planes of division are found in the body of a single *Microstoma*. In such an individual, one sees the original parent with its potential offspring—two children, four grandchildren

—all forming a series that moves about as the parent had done before the inception of fission.

In *Hydra* and *Microstoma* specialization, through physiological division of labor, has not resulted in the tissues becoming fixed. The potentialities of these tissues have not been greatly restricted. Or it may be that these tissues have not become stereotyped, as it were, through an adaptive response. *Hydra*, for example, because of being fixed at its base, cannot get away from some animals, like a snail, that would feed upon it. So by way of adapting itself to this negative condition, it suffers the snail to satisfy its appetite by eating, say, four-fifths of its body. Then, after the snail has gone, the remaining basal part of the polyp will regenerate such parts as were carried away by the snail. It matters not whether such power of regeneration comes about through a functional adaption or otherwise, the fact remains that this power of regeneration is conspicuous in *Hydra*.

Microstoma, too, shows some regenerative powers. The anterior end, involving the ganglia of *Microstoma*, may be removed and in time a new "head" with new ganglia will be developed. Moreover, ganglia and rudiments of a pharynx may arise at different levels of the body of *Microstoma* both as response to injury that prompts regeneration and to internal conditions that lead to propagation.

In this power of regeneration and in the asexual propagation of *Hydra* and *Microstoma*, it is seen that differentiation has not become deeply rooted. Even the germ-cells in these simple multicellular animals arise from widely distributed generalized types of cells. In short, there appears to be no sharp distribution and

segregation of peculiarly differentiated protoplasm so that only a certain set of cells can give rise to a particular tissue in a certain organ.

Just as there is no sharp and final localization of potential morphological features in these forms, so in *Microstoma*, where there is a well-differentiated central nervous system, there seems to be a generalized method of retaining records of the past. After a *Microstoma* has regenerated its ganglia it can carry out complex instinctive conduct involving experience with which the new ganglia have had no experience. From this it appears that the records of the past in *Microstoma* are not confined merely to its cephalic ganglia.

Both structurally and functionally, therefore, *Hydra* and *Microstoma* represent simple, generalized types. And yet they are capable of showing a marked degree of prescience as will be shown in the next chapter.

CHAPTER V

SIMPLE MULTICELLULAR ANIMALS LOOKING INTO THE FUTURE

The lack of complexity of the simple multicellular animals makes their prescience conspicuous. And yet in dealing with these animals in a strictly scientific manner this conspicuous characteristic must be ignored or overlooked. So long as the strictly scientific attitude is insisted upon, the prescience of any animal may not be given due recognition, for the proper attitude of scientific men toward such prescience is somewhat like the attitude taken toward the relation between cerebral organization in man and the consciousness of man. It is recognized generally that all modern work "has tended to show that in the cerebral hemispheres and, indeed, in the cortex of gray matter lies the seat of consciousness. . . . In the young infant the dawn of its mental powers is connected with and dependent on the development of the normal cortical structure, while in extreme age the failure in the mental faculties goes hand in hand with an atrophy of the elements of the cortex. If this were removed all the intelligence, sensation, and thought that we recognize as characterizing the highest psychical life of man would be destroyed, and abnormalities in the structure of this cortical material are accepted as the immediate causal factor of those perversions in reasoning and in character which are exhibited by the insane or the degenerate." The layman of this scientific age is kept

quite familiar with this objective side of man's psychology as a fact of science. But there is another phase of the relation between cerebral organization and consciousness which is not generally emphasized. This phase can be set forth here by continuing the above quotation from Howell. "The cortical gray matter, therefore, is the chief organ of psychical life, the tissue through whose activity the objective changes in the external world, so far as they affect our sense organs, are converted into the subjective changes of consciousness. The nature of this reaction constitutes the most difficult problem of physiology and psychology, a problem which it is generally believed is beyond the possibility of satisfactory explanation. For it is held that the methods of science are applicable only to the investigation of the objective—that is, the physical and chemical—changes within the nervous matter, while the psychical reaction is of a nature that cannot be approached through the conceptions or methods of physical science. In other words, there is a physiochemical mechanism in the brain matter which is capable of giving us a reaction in consciousness. The methods of physiology are adapted to the investigation of the nature of this mechanism, but the reaction in consciousness deals with a something which so far as we know is not matter or energy, and which, therefore, is not within the scope of physiological, or indeed, scientific explanation."[1] The prescience of man becomes a factor in his consciousness. Indeed Bergson has defined consciousness as the hyphen that connects the past and the future. So, to those who would limit

[1] "Text-Book of Physiology," William H. Howell, Fourth Edition, W. B. Saunders & Co., Philadelphia, 1911, pp. 183–4.

science to things ponderable, the consciousness of man may not properly be an object of science.

The billions of cortical cells of man may explain the many complex records of past experience that man retains and makes use of in adjusting his life to every day conditions; but, so far as I can see, no number of cells as mere material entities can be so arranged as to anticipate the future. No matter how complex the mechanism of molecules, prescience is never therein.

On the contrary an animal may be so lowly organized that it is but a mere "stomach" or alimentary sac provided with supplementary tentacles and yet show prescience. *Hydra* is such an animal. It is sometimes referred to as being but a stomach with accessory tentacles. The *Hydra* has its general surface armed with complex stinging threads that have been formed by certain cells of its outer tissue. These cells are known as cnidoblasts. The cnidoblasts arise through a modification of the generalized cells known as interstitial cells (Figs. 5, 6, and 8). A cnidoblast in elaborating a nematocyst is looking into the future or better its constructive efforts are directed towards the future; for in making a nematocyst it is providing an instrument of defense or of offense that the *Hydra* may eventually use. It is providing for a contingency that may present itself in the future. Just as a lad makes a trap with reference to the future, so the cnidoblasts elaborate nematocysts in order that the *Hydra*, as a whole, may at some future time either secure food or defend itself. In this case we have prescience carried out by living cells that in the end lose their lives in the process; for, with the discharge of the nematocyst, the cnidoblast is killed. Therefore, in the forma-

tion of nematocysts by the interstitial cells of *Hydra* we see these living units sacrificing themselves in a prescient manner with reference to the welfare of the individual polyp.

But the *Hydra's* interstitial cells also display prescient conduct when it comes to sexual propagation. Certain interstitial cells, during sexual reproduction, are suffered to be lost not in order that the future welfare of the colony of cells, of which they are members, may be cared for, but in order that another colony of cells may survive the present one. In other words a rather complex chain of phenomena are carried out by the *Hydra* by which a fertilized egg may result and from it a new *Hydra* develop. Most of these phenomena involve the interstitial cells of the ectoderm; but the endoderm likewise takes part in this function. Tanreuther has shown that at the inception of the gamete-formation the endoderm assembles locally an unusual supply of digested food. Over one of these regions of the endoderm, within which a great amount of food has been assembled, the interstitial cells divided frequently and in a definite manner. This involves a series of peculiar mitoses. The outcome of this cell-proliferation is a large number of small cells that become differentiated or metamorphosed to form spermatozoa. The nuclei of the cells, from which these spermatozoa have come, have suffered a loss of chromatin. A certain amount of the nuclear material has been reduced. Were it not for this when the nucleus of a sperm-cell were to unite with the nucleus of the egg at fertilization, the nucleus of the fertilized egg would have a double quota of nuclear material. Such accumulation of chromatin would thus occur at

each generation. To meet this contingency or to avoid the doubling of nuclear material at each generation of *Hydras*, that arises sexually, the spermatozoa have come down through a complex series of changes as greatly altered cells. The complexity of these phenomena is too great to be presented here. The reader may look up the phenomena of spermatogenesis as given in many text-books of biology and zoölogy. Moreover, while thus the individual sperm is prepared in such fashion as that the racial germ-plasm may be kept quantitatively and qualitatively constant, sperm-cells are produced in very great numbers in order that the contingency of nonfertilization of the egg may be avoided. In this effort to meet future conditions in a successful manner, the *Hydra* sacrifices many sperm-cells. So again we see the interstitial cells, in their prescience, acting vicariously through their lineal descendants.

But the prescience of the *Hydra* does not end here. Over a second region of endoderm, within which a great amount of food has been assembled, certain interstitial cells divide. After a certain number of divisions has taken place the resulting cells grow. There now seems to follow a struggle between these enlarged interstitial cells which results in one of them getting the upper hand over the others. As a result, the stronger one ingests the others and feeds upon them. Thus supplied with a special amount of food from the adjacent endoderm and with the food represented by the bodies of its sister cells, this strongest interstitial cell grows to be very large (Fig. 7, *g*) and lays down food in the form of yolk granules. It is now a full-grown egg. In the meantime it, too, has thrown off some of

its nuclear material in order that it will be prepared to accept a contribution of nuclear material from a sperm-cell without disturbing the quantitative and qualitative character of the racial germ-plasm. So in two ways this egg, or greatly enlarged interstitial cell, has shown prescience. In the first place, it has done this by elaborating a great amount of special food—deutoplasm or yolk—with which the developing embryo will be fed while it is unable to secure food for itself; in the second place, it has done this by avoiding the contingency of an undue accumulation of nuclear material—chromatin—that would take place at fertilization, had it not thrown out some of its own chromatin during oögenesis.

The contention might be raised that the *Hydra* in elaborating food, in the form of yolk, does not represent a looking into the future; but that this is but a record of the past of which the ovum and embryo now make use. One, for example, cannot argue that gill-slits are formed in the neck of the human embryo or that of the chicken in order that later the embryo may have two of them modified to form the Eustachian tubes of the ears. In this latter case, reference to the future is not so evident as is the record of the past. Atavism or racial experience overshadows what of prescience there may be in this transformation of gill-slits into Eustachian tubes. So likewise, the contention might be raised that if we could see the transition in the racial experience of *Hydra*, as in the case of the gill-slits of the human embryo, we would again realize that the record of the past overshadowed the apparent prescience that there is in *Hydra's* formation of yolk. I cannot see how such objection could be raised against

the prescience of *Hydra* in elaborating "stinging threads" but even in the case of yolk formation there is a series of facts that might be raised against the contention that has just been presented.

Standing just above the group of animals to which *Hydra* belongs, is the phylum Platyhelminthes (flatworms). These worms are by far less removed through differentiation from their *Hydra*-like progenitors than are the birds from their reptilian progenitors. This phylum of flatworms is divided into three classes. The simplest flatworms belong to the class Turbellaria. The class Turbellaria, in turn has two orders. The simpler Turbellaria belong to the order Rhabdocœlida. This order, Rhabdocœlida, has two suborders; the simpler—more primitive of these suborders being the Rhabdocœles. In connection with the contention raised above concerning yolk formation in *Hydra*, the manner in which yolk is elaborated in this narrow group of simplest flatworms—Rhabdocœles—becomes of interest.

In *Stenostoma* it appears that the yolk is formed within the endoderm that lies near the forming egg and is then transferred to the egg. In this way a great amount of food is stored up for the future development of the embryo. In *Microstoma* the egg takes food from the plasma of the mesoderm and shapes this into food for the future development of the embryo, while in the *Dalyella*, *Gyratrix*, and many other Rhabdocœles large "yolk-cells" are assigned the zygotes to meet the demand for food that will arise by the development of the embryo. It is hardly to be expected that within so restricted a group of flatworms, but little removed from *Hydra*, there could have been such widely differ-

ing racial experiences as to have led to the formation of structures that, in three different manners, would have brought about the same end, viz., the formation of yolk for the ovum and the embryo that will develop from it. In these Rhabdocœles, we find that in one genus, material of which yolk is to be elaborated, is taken directly from the enteron or alimentary canal; in a second genus, the material for yolk formation is taken from the plasma of the middle tissue of the body; while in a third genus, the yolk material is supplied by yolk glands. These three genera are more closely related, so far as their immediate phylogeny or ancestry is concerned, than are reptiles and birds. However, yolk-formation in the reptiles is similar to that in birds. In these two groups the formation of yolk might be held to be but a record of the past, since in both the reptiles and birds yolk arises in a like manner. In short, there is a contrast between the threefold manner of yolk elaboration in closely related genera of the Rhabdocœles, on the one hand, and the single method of yolk formation in the reptiles and birds on the other. In the Rhabdocœles, therefore, life's flux, since the origin of the different genera from some common ancestor, has resulted in the ova and their respective embryos being provided for along three different lines. This fact, for me, weakens the contention that yolk elaboration is directed not to the future but arises out of the past. The reader may accept either alternative; but he should bear in mind that no human records have ever been more than records of the past. Records, as such, are not directed toward the future.

To refer this action to racial experience does not explain the provident nature of it. A record of the

past is ever a record of the past; no matter how far back it may, as racial experience, be shunted in the ontological series so as to appear precocious, the fact remains that just as soon as this past experience is made use of or assigned to meet some future condition it is raised to a level where it is no longer a record of the past. In this adjusting of past experience to meet future needs is seen, then, the prescience that is involved when *Hydra* elaborates food for its future embryo. When we keep such facts as these in mind the burden of proof seems to be thrown upon the objector who raises the contention that in the formation of yolk there is but a record of the past involved and no reference to the future. A more detailed set of facts will be brought against this contention when I take up the reactions of *Amœba* in Chapter VII. And for the present I shall let the prescience stand before the reader as it is displayed in the *Hydra's* elaboration of nematocysts.

The prescience of *Microstoma* is more strikingly evident than that of *Hydra*. This prescience is indeed so conspicuous that one feels that there is a disparity between the degree of organization of matter displayed by this little Rhabdocœle and the provident conduct that it shows.

There are those who claim that our thoughts are but epiphenomena; that the brain secretes thoughts as the liver secretes bile. When such person is asked if a dog could lay intricate plans for the future such as man lays, he replies "No, the dog's cerebral cortex is not sufficiently highly organized for such complex effort." Ask a person, so satisfactorily saturated with the scientific attitude, if a dog, after having eaten a porcupine—quills and all—could conceive of the pos-

sibility of carrying the quills to his surface and therein hold them properly oriented in order that they might serve him as they had served the porcupine. Again the reply would be negative and the explanation would

FIG. 15.—Transverse section of *Microstoma*. Section taken through plane in which the legend line after *P*, in Figure 10, lies. *a*, two of *Hydra's* nematocysts within lumen of enteron. Other solid bodies are found with them in this lumen. The other solid bodies are rejected. *b*, a nematocyst of *Hydra* being carried from lumen of enteron to mesoderm by an endodermal cell; *c*, *c*, two nematocysts of *Hydra* lying within mesoderm without attending cells or cnidophages; *d*, an undischarged nematocyst at surface with its cnidophage the nucleus of which is shown; *e*, a partially discharged nematocyst; *en*, endoderm.

follow that the dog's cerebral hemispheres are not sufficiently highly organized to permit of such intricate planning for the future.

In the light of such scientific replies the conduct of *Microstoma* becomes significant; for in it there appears a disparity between the complexity of reaction and the complexity of organization.

Microstoma lives with *Hydra*. It has found the value of *Hydra's* nematocysts. I have frequently seen *Microstoma* severely stung by *Hydra* and sometimes the latter eat a *Microstoma*. *Hydra*, therefore, is a more dangerous animal to *Microstoma* than is a porcupine to a dog. Despite this fact *Hydra* is not avoided by *Microstoma*. On the contrary it is sought out for its nematocysts. For example, when a *Hydra* is found, the *Microstoma* paralyzes a part of its body before that region of the *Hydra* has had a chance to discharge its nematocysts. The paralysis is effected through a secretion that the *Microstoma* throws out from its mouth. The paralyzed part of the *Hydra* is then eaten by the *Microstoma*. Sometimes an entire *Hydra* is thus ingested. Within the enteron of the *Microstoma* all parts of the *Hydra* are digested except the nematocysts. When this phase of the process has been reached the nematocysts may be seen lying free within the lumen of the enteron (Fig. 15, *a*). Soon the endodermal cells lay hold of the nematocysts and ingest them as they do small bits of solid food. The nematocysts lie within vacuoles, that resemble food vacuoles, within

FIG. 16.—A partially discharged nematocyst of *Hydra* projecting from the ectoderm of *Microstoma* and having an attending cell of the latter's mesoderm, *c. m*, mesoderm; *e*, ectoderm with its cilia; *n*, nematocyst of *Hydra* discharged by *Microstoma*. ×1500.

the endoderm (Fig. 15, *b*). I have seen in living specimens the next phase of the process. The endodermal cell will now carry the nematocyst down to its base with the blunter end of the oval nematocyst directed ahead. In this position—blunter end first—the nematocyst is pushed through the base of the endodermal cell into the spongy mesoderm. Within the mesoderm of *Microstoma* the nematocysts are indifferently oriented (Fig. 15, *c*). They are here bathed by the plasma that fills the interstices of the mesoderm. Eventually about each nematocyst a wandering mesodermal cell

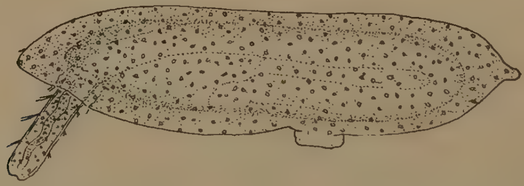

FIG. 17.—A "loaded" *Microstoma* swallowing an aquatic worm (annelid). The uniformly distributed small rounded bodies are nematocysts from *Hydra*. The internal pressure of the large worm upon the inside of *Microstoma* has caused the everting of the developing pharynx near middle of ventral side of *Microstoma*. (From Kepner and Helvestine.)

will crowd. This mesodermal cell ingests the foreign nematocyst and then transports it to the ectoderm of *Microstoma*. At this phase of the process as many cells are involved as there are nematocysts, each transporting a nematocyst. These cells, acting independently carry their respective nematocysts to the surface of *Microstoma* in such manner that the *Microstoma* comes to have nematocysts at its surface *uniformly distributed* and all properly oriented. Here the attending cells retain them indefinitely (Fig. 15, *d*, *e*), (Fig. 16), and (Fig. 17).

On each of two occasions I have found a *Microstoma*

that had but two to eight nematocysts in its body and at the same time had ingested such a large mass of food that it appeared that the animal could swallow no more food. In one of these cases the *Microstoma* when placed with a *Hydra* regurgitated some of the ingested food and within 12 minutes had eaten a part of the *Hydra*. The second specimen did likewise within twenty minutes. These observations suggest that the *Hydras* are not eaten primarily for food but as a source of supply of nematocysts.

This suggestion was followed by making a set of observations upon *Microstomas* that had their full supply of nematocysts. Such specimens may be said to be loaded (Fig. 17). Loaded specimens were now starved. By controls it was found that under laboratory conditions the *Microstoma* lived but about ten days without food. *Microstomas* that were but $^1/_3$ or $^1/_2$ loaded and starved a day would not accept *Hydra* soon. It would be a matter of days instead of minutes before a part of *Hydra* would be eaten. One of the fully loaded *Microstomas* was starved for ten days without accepting *Hydra*. Finally on two occasions I have succeeded in getting a loaded *Microstoma* to eat a *Hydra*. In the first specimen I observed that after the *Hydra* had been ingested the indigestible nematocysts were not taken up by the endoderm of this loaded *Microstoma* but were rejected or thrown out of the mouth as waste material. In the second example I had the good fortune to demonstrate the details of this rejection of nematocysts by a loaded *Microstoma* to Dr. Taliaferro of the University of Chicago.

So it appears that when a well-fed *Microstoma*, lacking its full complement of nematocysts, encounters

Hydra the latter is eaten and the nematocysts appropriated, carried to the ectoderm and there oriented and maintained by certain cells—the cnidophages—of *Microstoma's* body. On the other hand, it appears that when a *Microstoma* is loaded or has nearly its full complement of nematocysts it does not readily eat *Hydra;* and when it does the indigestible nematocysts of *Hydra* are regurgitated or rejected. All of this indicates that *Hydra* is eaten by *Microstoma* primarily for its nematocysts and not for the food that its body represents. The inference, that nematocysts of *Hydra* are appropriated by *Microstoma* in order that the latter may use them, is, therefore, warranted.

Microstoma does not spend these foreign structures recklessly. If a *Microstoma* be stroked with a fine needle the nematocysts at points of contact will oscillate to and fro, at right angles to the *Microstoma's* surface, in a most threatening manner. If this disturbance is kept up the animal will, in time, discharge some nematocysts from the disturbed region. No one can look at the threatening oscillation in and the final discharge of nematocysts from such a teased *Microstoma* without feeling that these must be used by the *Microstoma* under normal conditions.

To test this finally, loaded *Microstomas* were placed in hanging drops of water together with other small worms. Here it was seen that contact with these worms caused the *Microstoma* to oscillate its nematocysts at the various points with which the second kind of worm made contact. But the observations carried me beyond this, for I have been able to demonstrate to Dr. I. F. Lewis, Dr. W. H. Taliaferro, and Mr. Conway Zirkle such disturbing worms having been stung

and locally paralyzed by the nematocysts that *Microstoma* had thrown into their bodies. *Microstoma*, therefore, in its prescience, eats a *Hydra* primarily for its nematocysts; appropriates these stinging threads and maintains them properly oriented in order that it may, in case of demand, use them as defensive and perhaps offensive structures.[1]

It is sometimes held that man's prescience is imposed upon him in a mechanical manner because of his heredity equipment. His germ-plasm and soma are so constituted that a man can do no otherwise. Man to-day provides so well for his future food supply because his germ-plasm and social heritage are what they are. In short all the wonders that men work are due but to the "fortuitous concourse of atoms" and the "complex concatenation of circumstances" that have run parallel since the origin of the universe. Man's rational conduct, therefore, is but an epiphenomenon. According to this attitude, rational man is but matter raised to a high degree of complexity through a series of selecting guiding circumstances.

When, however, the organization of *Hydra* and *Microstoma* is kept in mind this position seems less tenable.

It is hard to think, for example, that in *Microstoma* no psychosis can take place without neurosis; for here there is but a low degree of centralization. Cells that carry out the various phases of the manipulation of the nematocysts act independently of the simple nervous system of *Microstoma*. The endodermal cell appropriates a nematocyst as an independent cell, and the

1 "Nematocysts of Microstoma," W. A. Kepner and John F. Barker, Biological Bulletin, Oct., 1924.

wandering mesodermal cell when it becomes a cnidophage is as independent of the direct action of the *Microstoma's* central nervous system as is a leucocyte of our own body independent of our central nervous system. Despite this fact, we see *Microstoma* displaying instinctive knowledge. This being the case, "No psychosis without neurosis" must be altered to read no psychosis without endodermosis and mesodermosis!

CHAPTER VI

TYPES OF UNICELLULAR ANIMALS

Unicellular animals are so different from ordinary multicellular animals, that when the average layman is told of their characteristics he marvels. His wondering mind raises questions such as these: "Can an animal, lacking central nervous system and organs of special sense, feel?" "Can an animal, without an alimentary canal, eat and grow?" "Can an animal, not having muscles and a skeletal system, move from place to place?" "Can an animal, not developing a reproductive system, propagate itself?" So marvelous are these creatures to a layman that he is tempted to see in them the details of the anatomy of higher animals. On one occasion I showed an East Indian student some of these under a microscope. It was his first experience with a compound microscope. He was a vegetarian and went away troubled because he had seen "fish" in water that he had thought free of animal life. Like Leeuwenhoek, his imagination had supplemented his eyes. Leeuwenhoek in looking at "Spermatic animalcula moving by vibrations of their tails," said "We may naturally conclude that these tails are provided with tendons, muscles, and articulations, no less than the tails of the dormouse or rat, and no one will doubt that these other animalcula which swim in stagnant waters, and which are no longer than the tails of the spermatic animalcula, are provided with

organs similar to those of the highest animals. How marvelous must be the visceral apparatus shut up in such animalcula."[1]

Leeuwenhoek, in 1675, gave an interesting description of one of the unicellular animals commonly found in stagnant water. He then wrote: "When these animalcula or living Atoms did move, they put forth two little horns, continually moving themselves. The place between these two horns was flat, though the rest of the body was roundish, sharpening a little toward the end, where they had a tayl, near four times the length of the whole body, of the thickness (by my microscope) of a spider's-web; at the end of which appear'd a globul, of the bigness of one of those which made up the body; which tayl I could not perceive, even in very clear water, to be moved by them. These little creatures if they chanced to light upon the least filament or string, or other such particle, of which there are many in water, especially after it has stood some days, they stood entangled therein, extending their body in a long round, and striving to dis-entangle their tayl; whereby it came to pass, that their whole lept back towards the globul of the tayl, which then rolled together Serpent-like, and after the manner of Copper or Iron-wire that having been wound about a stick, and unwound again, retains those windings and turnings. This motion of extension and contraction continued awhile; and I have seen several hundreds of these poor little creatures within the space of a grain of gross sand, lye cluster'd together in a few filaments."[2]

[1] Quoted from Calkins' "The Protozoa," page 6, New York, 1901.
[2] Ibid.

What this pioneer microscopist really saw was not an animal composed of organs, tissues and cells, but a little single-celled creature called *Vorticella.* Since 1838, when Schleiden and Schwaun were able to make their conspicuous generalization that all living things present a certain unit of structure that is composed of protoplasm, men have ceased to look for complex organs in all plants and animals. However, as late as 1838 Ehrenberg was insisting that *Vorticella* had stomach, muscles, etc.

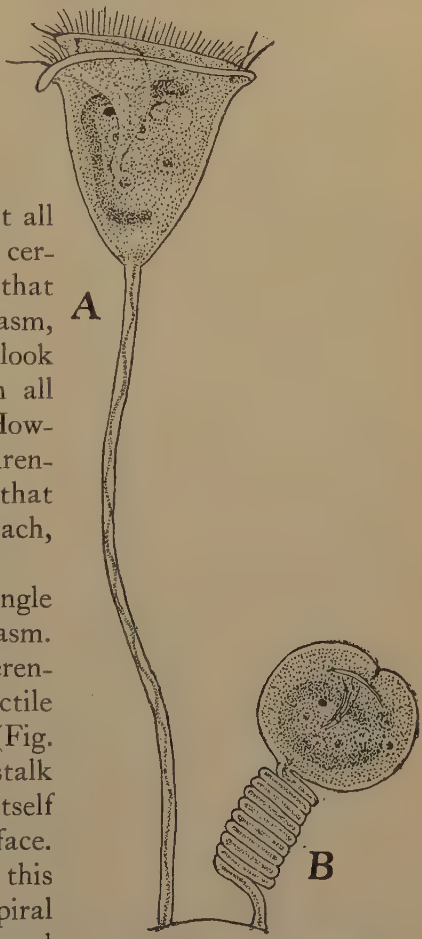

FIG. 18.—*A*, *Vorticella* expanded; *B*, a specimen contracted.

Vorticella is but a single unit or cell of protoplasm. Its cell-body is differentiated into a contractile stalk and body-proper (Fig. 18). By means of the stalk the animal attaches itself to some submerged surface. About the free end of this cell there runs a spiral groove which is bordered by cilia. The deeper end of this groove leads to a mouth and gullet through which food particles are taken into the body. Along

the spiral groove fine, vibratile protoplasmic filaments or cilia are arranged. These cilia beat the water in such fashion as to set up a vortex within which it carries food and other objects into the spiral groove or peristome. These vortices are maintained while the animals lie with their stalks extended. If some unfavorable stimulus be brought to bear upon the animal, it attempts to avoid the stimulus by vigorously contracting its body and stalk. As a result, the entire animal suddenly darts back against the surface to which it is attached. The stalk at such times is thrown into a spiral (Fig. 18, *B*). The spiral is eventually unwound and the animal opens up on its extended stalk again and renews its search for food. It was such opening and closing of the stalk that Leeuwenhoek refers to in the first description of *Vorticella*.

While *Vorticella* does not always live as a fixed animal and under certain conditions moves freely from place to place, it does not serve as well as a typical unicellular animal as does *Paramecium*.

Paramecium caudatum is found in stagnant water very generally. It varies in size from 1/10 to 1/3 mm., so that the largest individual can readily be seen by the naked eye as a freely-moving, milky-white speck in the water. When seen under the compound microscope this small animal is found to have a definite contour. Its general shape suggests that of a slipper. However, the opening of the slipper, in this case, is not a real opening. The feature that suggests the opening of a slipper is a shallow groove (oral groove). This groove passes from the "heel" end of the slipper animalcule along a wide spiral path two thirds (more or less) of the way toward the "toe" (Fig. 19). This

spiral groove is called the oral groove or *peristome*, because at its "toe" end it surrounds the mouth.

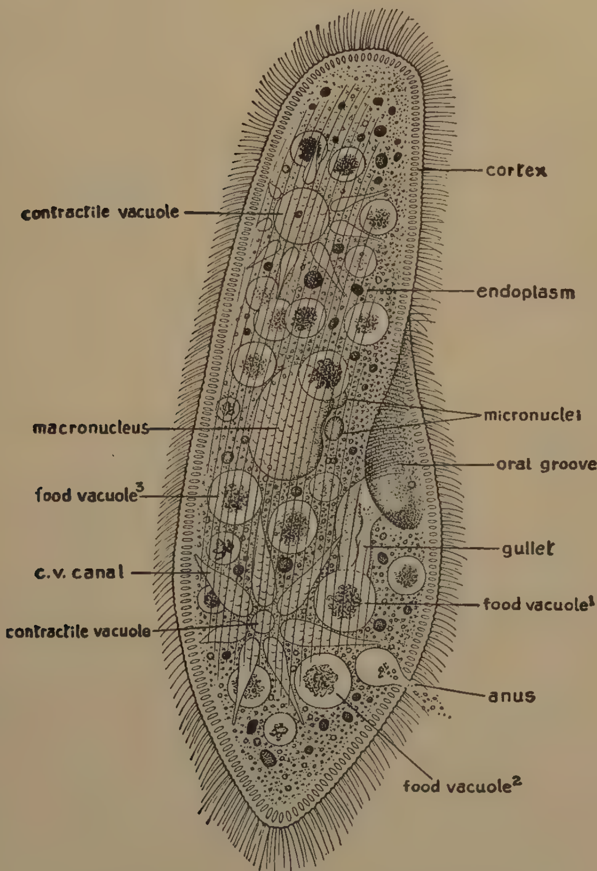

FIG. 19.—"*Paramecium aurelia.* Note especially the two micronuclei. Redrawn after Pfurtscheller wall chart." (From Newman.)

The mouth opens into a *gullet* within which is a delicate membrane that, in undulating, helps to drive food and water through the gullet. The peristome is lined with

cilia that set up vortices in the water and thus drag food and water toward and along the peristome to the mouth. As the objects pass along the peristome, they are tested by the latter; so that, when the animal needs food, the food particles will be accepted while the nonfood objects will be rejected as a rule. However, *Paramecium* may accept inert objects, such as particles of carmine or India ink. Another unicellular animal, closely related to *Paramecium*, *Stentor*, "discriminates in food with a precision that is matched only, so far as we know, by that of the higher animals." [1] The peristome with its cilia thus act as an organ of special sense and of prehension. But in addition to this the general surface of the body may also receive physical and chemical stimuli and respond to them. Thus the external layer of protoplasm in this unicellular animal has to function as a region of prehension and perception. Moreover this outer layer, or *ectoplasm*, elaborates fine vibratile protoplasmic processes or *cilia* that are distributed uniformly over the body. These cilia constitute the animal's organs of locomotion.

So far, it is seen that the ectoplasm has to do with prehension, perception, and locomotion. The animal cannot lay hold of an object so minute as one of the bacteria upon which it feeds without expending energy; it cannot perceive or take notice of the difference between food and nonfood, and it cannot move from place to place without expending energy.

The direct source of the energy that this or any typical animal expends lies in the oxygen, food, and water that it takes into its body and appropriates. The

[1] A. A. Schaeffer, Trans. Tennessee Acad. of Sc., 1910–1913, p. 37.

oxygen is taken into the animal's body through the general surface. Food and water, as has been stated above, are delivered to the inner granular layer of the protoplasm by means of the gullet. A droplet of water grows at the end of the gullet, as water containing bacteria is thrown through the gullet. This growth is similar to that that takes place at the end of a filled pipette when one gently presses the bulb. Eventually this droplet becomes so large that it drops off the end of the gullet into the endoplasm. Another droplet of water, containing bacteria next forms and grows until it too drops off into the endoplasm. But it must not be inferred that the food vacuole's formation is passive. This, too, is a regulated process. Each droplet thus formed is called a food vacuole. Thus a *Paramecium* in feeding delivers its food and water into the posterior third of its body. This is the least active region of its body. Most work is being done by the anterior third and the rate of metabolism (as Miss Hyman showed) is highest in the anterior third. This presents a striking situation in that the least active region is directly supplied with food, whereas the most active region is remotest from the direct supply of food. As an unicellular animal it can have no organs of circulation. In this animal, however, the endoplasm becomes a circulatory medium. It is kept in constant motion though its rate may vary. The currents of streaming endoplasm go anteriorly along the dorsal side of the body and posteriorly along the ventral side (Fig. 20). Thus by a flowing of the endoplasm, termed *cyclosis*, the food vacuoles are carried about throughout the interior of the *Paramecium*. As a food vacuole is thus carried about, enzymes are thrown into

it by the endoplasm and these dissolve or digest the food. The digested food and some of the water will be taken up from the food vacuole and delivered to the endoplasm. In time only a bit of indigestible matter and some water are left and these will be discharged at the "anal spot" or anus of the cell (Fig. 19). Thus the process of alimentation, involving digestion and absorption, is effected by the endoplasm. The food thus delivered to the endoplasm will be distributed to all parts of the cell and therein assimilated.

But just as in prehension, perception and locomotion

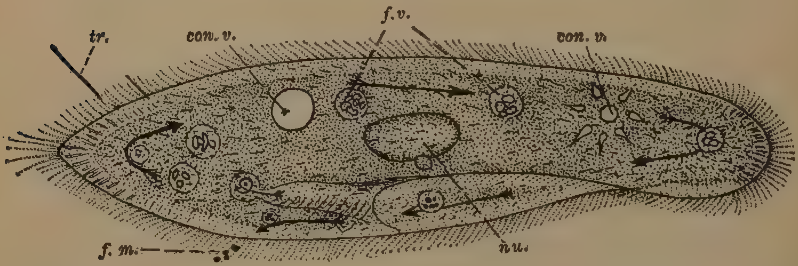

Fig. 20.—"Individual of *Paramecium caudatum*. Arrows show course of food vacuoles (*f. v.*). *nu.*, nuclei; *con.v.*, contracting vacuoles, one empty and one full; *f. m.*, fecal matter; *tr.*, discharged trichocyst. × 375." (From Dahlgren and Kepner.)

an expenditure of energy is demanded, so, in alimentation, food distribution and assimilation, a certain amount of energy is expended. The energy that an animal thus makes use of is obtained through a breaking down of some of its own body-substance. Through such breaking down process, energy is not only liberated but waste by-products are elaborated. These by-products are carbon dioxide and waste nitrogenous material. Cell structures that take in oxygen, water and food have been mentioned. The same cell-region—the ectoplasm—that takes in oxygen, throws off car-

bon dioxide. The ectoplasm is thus a real respiratory protoplasm. The waste nitrogenous material is thrown off by two pulsating vesicles or contractile vacuoles. Associated with each contractile vacuole is a set of radiating canals which drain the waste nitrogenous material into the vacuole (Fig. 20, *con. v.*). The waste nitrogenous material is discharged from the contractile vacuole through a pore in the ectoplasm (Fig. 21).

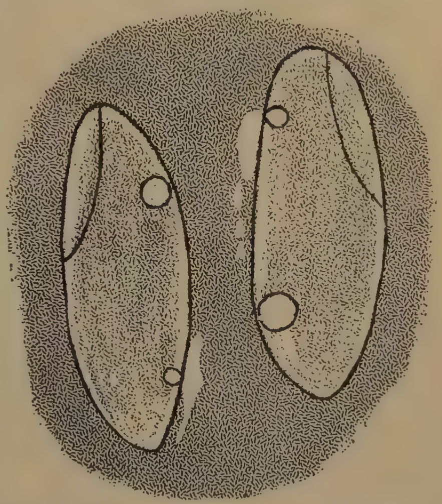

FIG. 21.—"Two infusorians swimming in a solution of India ink. The matter discharged from the pulsating vacuoles may be temporarily seen as an irregular area of clear fluid next to the body and surrounded by the darkened water." (After Jennings, from Dahlgren and Kepner.)

A living *Paramecium*, therefore, is continually taking into itself oxygen, water, and food by means of which it builds up the substances of its body. In this building-up process a certain amount of energy has been locked within the protoplasmic structure of the cell. The building-up process of a cell is known as *anabolism*.

On the other hand, a living *Paramecium* is continually breaking down some of its protoplasm and liberating energy and incidentally elaborating water, carbon dioxide and waste nitrogenous material. This breaking down process is known as *katabolism*.

So far reference has not been made to a certain protoplasm that is found in every typical living cell. Katabolism is not directly dependent upon a certain mass of dense protoplasm that is found in every typical living cell. This mass of dense protoplasm is known as the *nucleus*. The nucleus is so generally present in cells that a living cell is defined as a nucleated mass of protoplasm. The nucleus is a protoplasm that plays an important rôle in the life of the cell. Without it a cell may continue to carry on katabolic functions until the available energy becomes exhausted. But a typical cell cannot live long as a running-down organism without its nucleus. It has been shown by frequent experiments that the building-up process or anabolism depends upon the nucleus. In the nucleus (Fig. 19) of *Paramecium* we have a region of dense protoplasm that takes an important part in anabolism.

In having a nucleus, *Paramecium* is like any typical cell of one's own body. In having a definite shape it again resembles a cell taken say from the epithelium of one's intestine or a rod or cone cell of one's retina. Neither the intestinal cell nor the retinal cell, however, live independently. On the contrary they are highly specialized individuals in a multitudinous colony of cells. Each, therefore, displays fewer cell structures than does *Paramecium*. *Paramecium* must be looked upon as an unicellular individual that in itself must perform the functions that the various cells of one's body have divided among them. It is remarkable to see how readily and well all these elemental functions are carried out by *Paramecium*.

Its efficiency is due perhaps more to its having a definite shape than to any other structural feature; for

an unicellular animal having no definite shape has no definite organs of prehension, perception, and locomotion.

There are such unicellular animals, a good example of which is *Amœba proteus*. This little animal lacks all the features that men usually consider to be characteristic of an animal. It has neither fins, feet, nor

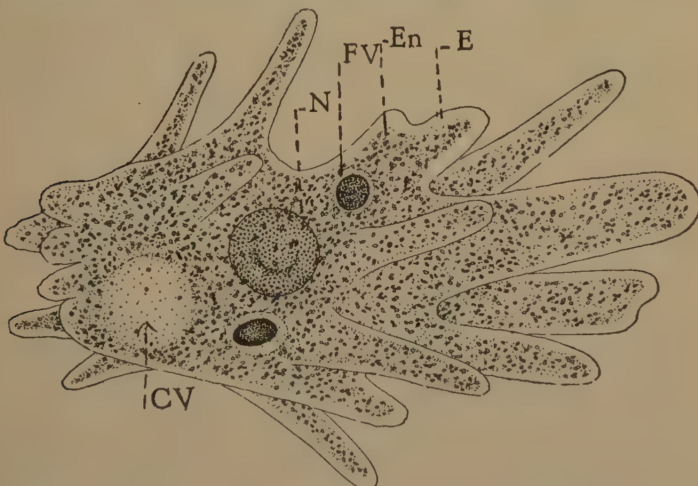

FIG. 22.—*Amœba proteus*. *N*, nucleus; *En*, endoplasm; *E*, ectoplasm; *CV*, contractile vacuole; *FV*, food vacuole.

feathered wings. It has neither muscular nor skeletal system. There is neither an organ of special sense to guide it, nor a nervous system with which it might coördinate its activities. It lacks even parents. Indeed it is much like Carlyle's French revolutionist *sans* this, *sans* that, *sans* even trousers—without this, without that, without even trousers; for it is but a small, shapeless mass of naked, nucleated protoplasm (Fig. 22).

An active *Amœba* drifts along some submerged surface in a manner that suggests the drifting of a cloud in the sky. Its shape is constantly changing as does that of a drifting cloud and yet this change of form is within a certain wide range; so that no haphazard outline would necessarily represent its contour.

Next to its ever-changing contour, its protoplasmic differentiation is perhaps its most marked feature. In an *Amœba's* body we meet with a threefold differentiation of protoplasm. There is an outer layer of protoplasm of varying thickness. This layer is homogeneous in texture, highly translucent and fairly dense. It is called the *ectoplasm*. The inner layer is densely granular. The granules vary in size and shape, so as to give the inner layer a heterogeneous appearance and to render it opaque. The third protoplasmic region is the nucleus (Fig. 22, *n*). Like *Paramecium*, it, too, is a cell in that it has a nucleus.

But how does an animal, so peculiar, move from place to place, and select and swallow its food? We need say little about the other details of an *Amœba's* life for they resemble those of *Paramecium*.

The movement of an *Amœba* is a fascinating phenomenon to observe. On one occasion I showed a fourteen year old lad an *Amœba*. In his surprise he spoke up, "Oh, look at that strange animal how it puts out an imaginary part of itself and then flows into it." His description was not bad. No real satisfactory description of an *Amœba's* locomotion has been given. If one keeps under observation a quiet specimen, it will be seen that from its side an outgrowth of clear ectoplasm will appear. Into the projected ectoplasm granular endoplasm will stream. The ectoplasm at

the end of the advancing endoplasm continues to be projected so that there arises on the side of the body an elongated structure composed of ectoplasm and endoplasm. This elongated protoplasmic body is termed a *pseudopodium* or "false foot." Several such pseudopodia may be forming synchronously. The *Amœba* moves by flowing into these pseudopods that it has thrown out. So one may say that an *Amœba* moves from place to place by flowing out of itself into itself.

Bütschli (1892) and Rhumbler (1898), in observing the flowing granules within the endoplasm of an advancing *Amœba*, supposed that they saw not only a forward axial current, but also that this axial current was deflected, at the anterior margin of the *Amœba*, peripherally to form returning lateral currents (Fig. 23).

FIG. 23. — "Diagram of currents in a progressing *Amœba limax*, after Rhumbler, 1898." (From Jennings.)

It happens that such a system of currents is set up within a drop of any fluid when the surface tension of the drop is lowered at a point. When the equilibrium of the surface tension is thus disturbed, an axial current arises within the drop and flows towards the point of reduced surface tension; from this point peripheral currents diverge and flow back laterally. A conspicuous analogy was thus apparent between the system of the currents that Bütschli and Rhumbler described in moving *Amœbæ* and those seen in a drop of fluid that was flowing over its substratum because of having had its surface tension's equilibrium disturbed.

Mechanists laid hold of this analogy and believed that in it was to be seen the explanation of vital

movement. Vital movement could thus be reduced to terms of physics. So late as 1905 Loeb wrote "As a criterion for 'living matter' we might use the irritability or spontaneity. But as the 'spontaneity' of living matter is in its simplest form (in *Amœbæ*) apparently not different from the physical phenomenon of spreading, for this criterion the limits of divisibility of living matter coincide with the limits of purely physical phenomena."[1]

Jennings (1904) failed to see the reverse lateral currents within an advancing *Amœba*. He felt convinced, after most painstaking observations, that Bütschli and Rhumbler must have been the victims of an illusion. His work fully confirmed the observations of Wallich (1863), who said "It is only necessary to watch a specimen of *Amœba* carefully to become convinced that the appearance of a returning, as well as an advancing, stream of granules is merely illusory. The stream, it will be observed, is invariably in the direction of the preponderating pseudopodial projections. The particles simply flow along with the advancing rush of protoplasm. There is no return stream, but the semblance of one is engendered by one layer of particles remaining at rest whilst another is moving past them."

The analogy between an advancing drop of fluid, moving by means of an altered condition of its surface tension film, and moving *Amœba* breaks down in the light of the observations of Wallich and Jennings.

But these are not the only observations that stand in the way of the applicability of this analogy. Del-

[1] Loeb, Jaques (1905), "Studies in General Physiology," University Chicago Press, p. 321.

linger (1906) devised a method of observing an *Amœba* from the side, so that he could look under the animal as it moved over some surface. In this manner, he saw that *Amœba proteus* would throw out a pseudopod free of the substratum (Fig. 24). Eventually, however, the end of this advancing, arching pseudopod would become fixed to the substratum. The body-proper,

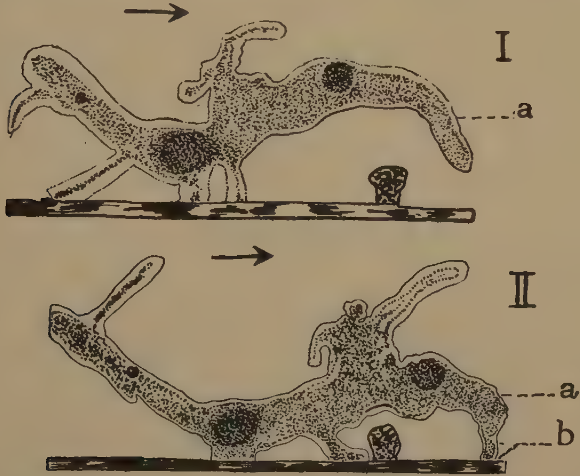

Fig. 24.—Two positions of an *Amœba* advancing in the direction indicated by the arrows. *I* shows a pseudopod, *a*, being thrown over and beyond an inert object. In *II* pseudopod, *a*, has been fixed to substratum at *b* and the body-proper has been dragged forward by the contraction of *a*. (From Jennings. After Dellinger.)

which up to this time had been fixed to the substratum would be loosened. The pseudopod would now contract, and being fixed at its distal end would drag the nonattached body-proper up toward its own attached end. This observation presents conditions that are widely removed from those found in an advancing droplet of liquid.

Mast and Root (1916) observed that an *Amœba proteus* can constrict a *Paramecium* and thus cut it

into two pieces. After having made this observation, they had some physicists study the viscosity of the *Amœba* and determine how much energy expressed in dynes would be available at the surface of a body of the viscosity of *Amœba.* In the meantime they determined the amount of energy in terms of dynes that was needed to sever a *Paramecium* with a fine glass

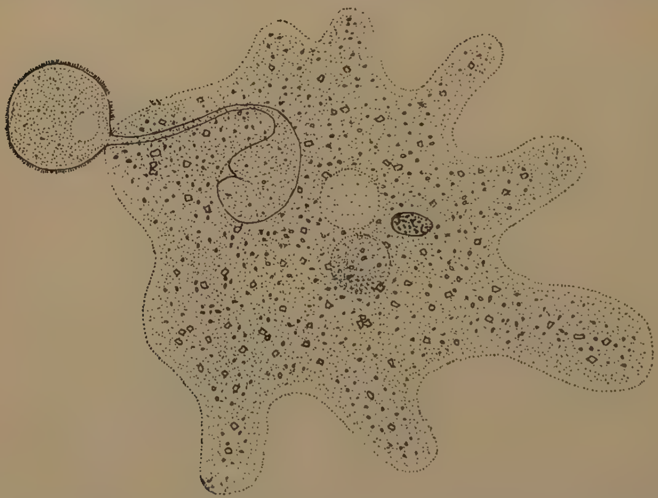

Fig. 25.—An *Amœba* attempting to ingest a *Paramecium.* The *Paramecium* has been greatly drawn out in its mid-region and yet no erosion of the ingested part of *Paramecium,* by digestive enzymes, had taken place; for when the *Amœba* rejected the *Paramecium,* the constricted region was elastic and had a uniform surface. (From Kepner and Whitlock.)

rod. They found that it required ten times more dynes to sever a *Paramecium* than would be available through surface tension forces. Mast and Root did not take into account the possibility that enzymes may have aided in the constriction of *Paramecium* by *Amœba.* An observation by Kepner and Whitlock (1921) indicates that enzymes are not involved in

this constriction. They saw a *Paramecium* that had been almost severed by an *Amœba* (Fig. 25). When this ciliate was rejected it showed no signs of erosion; moreover, there was as yet a certain degree of contractility of the ectoplasm in the constricted part of the *Paramecium's* body.

The work of Bütschli and Rhumbler, therefore, instead of setting aside the earlier observations of Wallich, did little more than stir up a "tempest in a tea-pot" over the supposed adequacy of *surface tension forces* in explaining the locomotion of *Amœba*.

Some interesting observations made by Schaeffer (1920) and Edwards (1923) have set Mast to studying the *Amœba's* locomotion. Mast (1923) has given us the latest and, withal, the best hypothesis extant concerning the *Amœba's* locomotion.

In studying *Amœba proteus*, Mast followed Schaeffer (1917), Seifriz (1918), and Edwards (1923) in maintaining that there are three regions to an *Amœba's* cytoplasm: "(1) A central elongated fluid portion; (2) A solid layer surrounding the fluid portion; (3) A very thin elastic surface or membrane. The first I shall designate the *plasmasol*, the second the *plasmagel*, and the third the *plasmalemma*."

The plasmagel has two regions, one belonging to the ectoplasm or ectosarc and the other belonging to the endoplasm or endosarc. The former is called the hyaline plasmagel. This is a complete sac (Fig. 26). The latter is called the granular plasmagel and forms a nearly complete sac (Fig. 26). The wall of the granular plasmagel is broken only at the advancing tip of the animal or of its advancing pseudopod (Fig. 26).

Having observed the above morphological details,

Mast explains the locomotion of an *Amœba* in the following manner: "During locomotion the plasmasol is continuously actively flowing forward into the enlargements near the tips of the pseudopods just in front of the opening in the granular plasmagel sac, and at the edge of this opening it continuously changes from a sol to a gel, that is, the sac of granular plasmagel is extended forward by material from the plasmasol

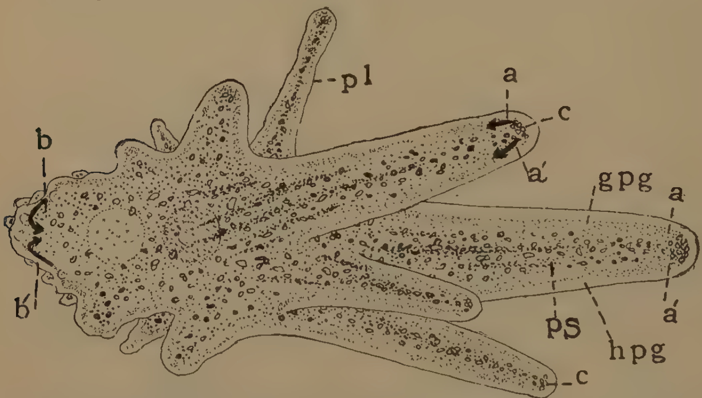

FIG. 26.—*Amœba proteus.* To illustrate Mast's conception of the structure of a moving specimen. Endosarc is composed of plasmasol (*ps*) and *granular plasmagel* (*gpg*). Ectosarc is composed of *plasmalemma* (*pl*) and *hyaline plasmagel* (*hpg*). *a* and *a'*, regions in which the advancing plasmasol has broken through the sheath of granular plasmagel; *b* and *b'*, region in which the granular plasmagel is being converted into plasmasol.

deposited all along the edge of the opening in it, much as a chimney might be extended by carrying brick and mortar up through it and depositing them on the wall surrounding the opening. At the posterior end the granular plasmagel is continuously going into solution on the inner surface where it comes in contact with the plasmasol.

"If a given granule in the plasmasol is continuously observed it can be seen to move forward in the neigh-

borhood of the central axis of the *Amœba* until it reaches the enlarged portion near the tip of a pseudopod and then to deflect outward where it sooner or later comes in contact with the edge of the opening in the sac of the granular plasmagel where it is caught in the gelatin of the fluid in which it is suspended and becomes stationary in reference to points outside, regardless as to whether it is to the right or the left or above or below the plasmasol. As more and more substances from the plasmasol are deposited at the anterior border of the granular plasmagel the *Amœba* moves forward and the observed granule approaches the posterior end where it sooner or later comes to the inner surface of the plasmagel. Here the substance in which it is imbedded goes into solution carrying the granule into the plasmasol in which it is again transported to the anterior end where it again enters the plasmagel, etc.

"The hyaline plasmagel moves continuously with the granular plasmagel, there being no sharp line of demarcation between them. It goes into solution at the posterior end being transformed with the granular plasmagel in which it is carried forward to the enlargements near the tips of the pseudopods. Here it changes to a gel and is deposited at the anterior surface immediately below the central portion, thus continously building up the sac of hyaline plasmagel by a sort of interpolation or imbibition. In this way the plasmagel is extended at the anterior end as rapidly as it is broken down at the posterior end, the plasmasol changing into plasmagel at one end and the plasmagel into plasmasol at the other.

"The plasmalemma is highly elastic, fairly tough and sufficiently differentiated from the plasmagel to

admit of free movement over it. As the *Amœba* moves forward the plasmalemma on the upper surface moves forward sliding over the plasmagel and turning down at the anterior end where it comes in contact with the substratum to which it adheres. Here it remains stationary in reference to points outside and points in the plasmagel until, owing to forward movement of the *Amœba*, it reaches the posterior end where it moves upward and forward again, like the drive belt in a caterpillar engine. In free pseudopods or in *Amœbæ* attached only at the posterior end it remains stationary or moves forward at the same rate on all of the surfaces. There is no evidence indicating that the plasmalemma is transformed into plasmagel or plasmasol except in the formation of food-vacuoles. It appears to be a fairly permanent structure. That it is highly elastic is evident from the fact that it is continuously readjusted so as to fit the multifarious changes in form observed in this organism. When a pseudopod is extended into the water free from the substratum, the plasmalemma is stretched out. It is not built up at the tip like the plasmagel for particles adhering to it can be seen to move forward on all surfaces while particles in the plasmagel are stationary in reference to points outside. What then are the factors involved in locomotion?

"The plasmasol is hypertonic and the plasmagel and the plasmalemma are semipermeable. This results in an excess inflow of water and a stretching of these layers until their elasticity equals the diffusion pressure and a state of equilibrium is reached with considerable outward pressure. When a pseudopod is formed the granular plasmagel liquifies locally and the

hyaline plasmagel in the same region softens. This produces a local decrease in the elasticity of these layers with the formation of a protuberance, a pseudopod. As this is formed there is a contraction, especially at the posterior end, resulting in forward movement of the plasmasol: this contraction is confined largely to the granular plasmagel, for the hyaline plasmagel and the plasmalemma in this region are frequently thrown into folds, showing that the inner surface of the plasmagel decreases more than the outer. As plasmasol moves forward and the plasmagel inward at the posterior end, the inner surface of the latter goes into solution, and as it goes into solution it swells resulting in a continuous forward push. There are, therefore, two forces involved in the flow of the plasmasol, the elasticity of the plasmagel and solution or imbibition pressure resulting in the continuous change of plasmagel to plasmasol at the posterior end. As the plasmasol reaches the anterior end it changes to plasmagel as previously described with a decrease in volume. This also tends to induce forward flowing in the plasmasol. All of these processes being continuous there is a continuous forward flow.

"The plasmalemma is of no significance in the mechanics of locomotion except in so far as its adhesion to the substratum makes forward movement possible. It is so elastic compared with the plasmagel that contraction and expansion in it are relatively unimportant. This becomes evident especially in high temperature when the hyaline plasmagel at the tip of the active pseudopods often suddenly breaks. When this occurs the plasmasol immediately back of it can be seen to rush through the break and stretch the plasmalemma

forming a prominent bulge. This results in a decrease in the outward pressure, and in the turgidity of the whole system, after which a new layer of hyaline plasmagel forms under the extended plasmalemma again increasing the strength of the wall at this point until an increase in turgidity to normal is possible.

"The fundamentals in locomotion in *Amœba* consist of the following: (1) Hypertonic solution surrounded by a semipermeable membrane resulting in turgidity. (2) Local swelling of the plasmagel at the tip of the forming or advancing pseudopods with a decrease in elasticity. (3) Contraction in the rest of the plasmagel with liquefaction on the inner surface at the posterior end resulting in forward flow of the plasmasol. (4) Gelation of the plasmasol at the outer posterior border of the anterior enlargement of the plasmasol forming new granular plasmagel and at the anterior surface of this enlargement forming new hyaline plasmagel. (5) Adhesion of the plasmalemma to the substratum."

This is a very carefully worked out hypothesis concerning locomotion in *Amœba*. In a remarkable manner it explains the observed facts. And yet it does not wholly explain the phenomenon of locomotion in this relatively simple animal. Mast goes on to say that "these processes could furnish enough energy to account for the phenomena observed in the behavior of *Amœba*. The energy doubtless originates in oxidation and other chemical changes in the organism. But how it is transformed from this form into the forms in which it manifests itself in the perceptual processes associated with locomotion is not clear. Osmotic tension is probably maintained in the same way that it is in other cells. Gelation and solution are probably

due to chemical changes associated with metabolism, the former being due to increase in acidity, the latter to increase in alkalinity. The principal problem before us concerns an explanation of the regulatory nature of these phenomena."

Apart from the regulatory nature of locomotion, Mast's hypothesis has carried us far toward an explanation of locomotion—the simplest phenomenon of life in an *Amœba*—one of the simplest animals. The movement of any body, be it inanimate or animate, is a proper subject for scientific investigation, in that it involves matter and space. As an object of science, therefore, the movement of *Amœba* will some day be reduced to terms of physics and chemistry. Mast's hypothesis has carried us far toward such solution. But science has not as yet given us an adequate explanation of *Amœba's* locomotion. Until, therefore, this simplest vital phenomenon in an *Amœba* has been reduced to terms of physics and chemistry, it is too early to claim that the facts of the psychology of man have been reduced to physical and chemical formulæ. And if there should be other than physical and chemical phenomena in life, there may be a basis for man's hope in personal immortality.

Locomotion of *Amœba* may be effected by any endoplasmic region. So likewise any region of an *Amœba's* ectoplasm may be involved in distinguishing the difference between what is food and what is not food. If an *Amœba* happens to have one pseudopod encounter a granule of sand at the same time that a sccond pseudopod comes in contact with a particle of food, the sand will be avoided while the food particle will be surrounded and thrown into the endoplasm together

with a little water. Of course whether an *Amœba* will ingest food depends upon the needs of the *Amœba* at the time food is encountered. Food will not be accepted if the *Amœba* does not need it. As William James has indicated, an *Amœba* does not of necessity have to ingest food when it encounters it; for if that were the case, all *Amœbas* would early fill a glutton's grave.

In contrast to *Paramecium* and some other ciliates, *e. g.*, *Diplodinium ecaudatum*, which has recently been described by Sharp, *Amœba* is relatively simple (Fig. 27).

An *Amœba*, however, is not the simplest type of animal. Most animals have their bodies formed of organs; the bodies of relatively few are but aggregates of tissues, as for example *Hydra;* while there are many that have unicellular bodies. *Paramecium* and *Amœba* are, of course, representatives of these. The simplest type of animals is not, strictly speaking, unicellular; for they do not have a centralized nucleus. These might be called protoplasmic animals in contradistinction to unicellular, tissue-, and organ-animals.

An example of a mere protoplasmic animal is *Leptophrys elegans* of Hertwig and Lesser. This beautiful microscopic animal has a body of protoplasm that is differentiated into a translucent homogenous ectoplasm and a granular somewhat vacuolated endoplasm (Fig. 28). Its locomotion is effected by more or less active amœboid movement. An active large individual tosses about very much as a cloud of smoke is distorted by a current of air. This drifting, ever-changing mass of protoplasm maintains a thickness of about 5 to 10 microns.

Sometimes after this animal has ingested a great

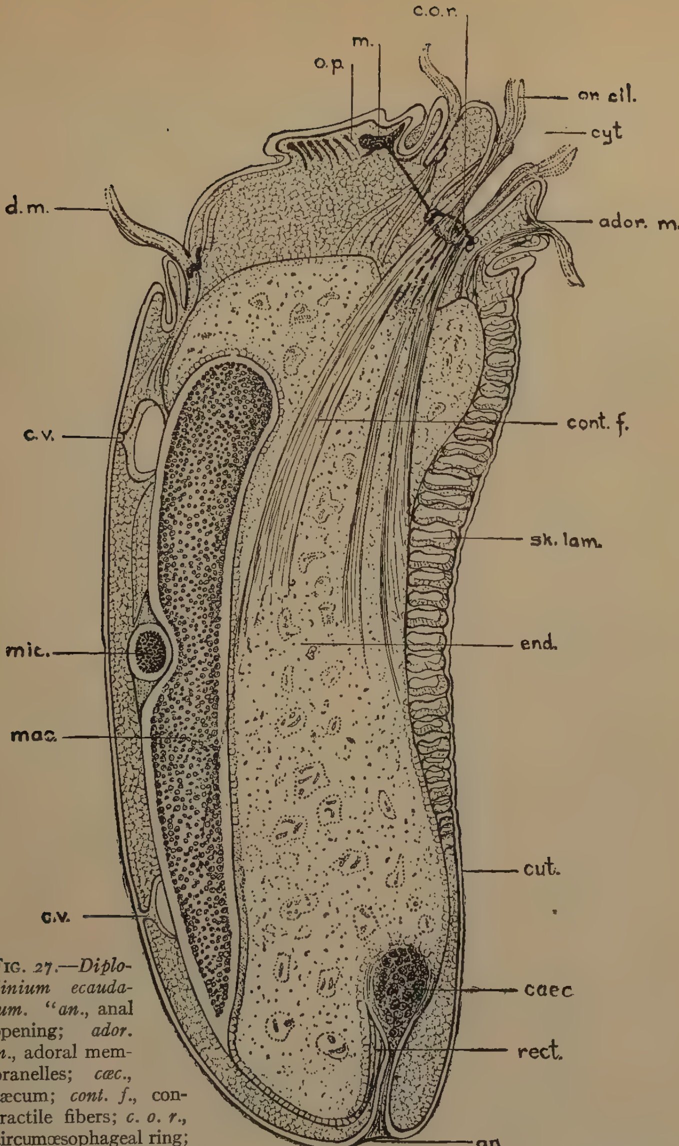

FIG. 27.—*Diplodinium ecaudatum.* "*an.*, anal opening; *ador. m.*, adoral membranelles; *cæc.*, cæcum; *cont. f.*, contractile fibers; *c. o. r.*, circumœsophageal ring; *cut.*, cuticle; *c. v.*, contractile vacuole; *cyt.*, cytostome; *d. m.*, dorsal membranelles; *end.*, endoplasm; *m.*, motorium; *mac.*, macronucleus; *mic.*, micronucleus; *o. p.*, operculum; *or. cil.*, oral cilia; *rect.*, rectum; *sk. lam.*, skeletal laminæ. ×1100." (From Hegner and Taliaferro after Sharp.)

amount of food, it assumes a rounded contour (elongated or spherical depending upon the shape of food

FIG. 28.—*Vampyrella* (*Leptophrys* H. and L.) *elegans*. A protoplasmic animal that lacks a concentrated nucleus. ×750.

bodies) and builds a cyst membrane about itself (Fig. 29 and Fig. 30). Within this cyst the green or brown food is digested and as this food is digested the color

changes to a pretty brick red. When this brick red food is taken up by the endoplasm, the endoplasmic granules take on a similar color.

When the process of alimentation is completed the

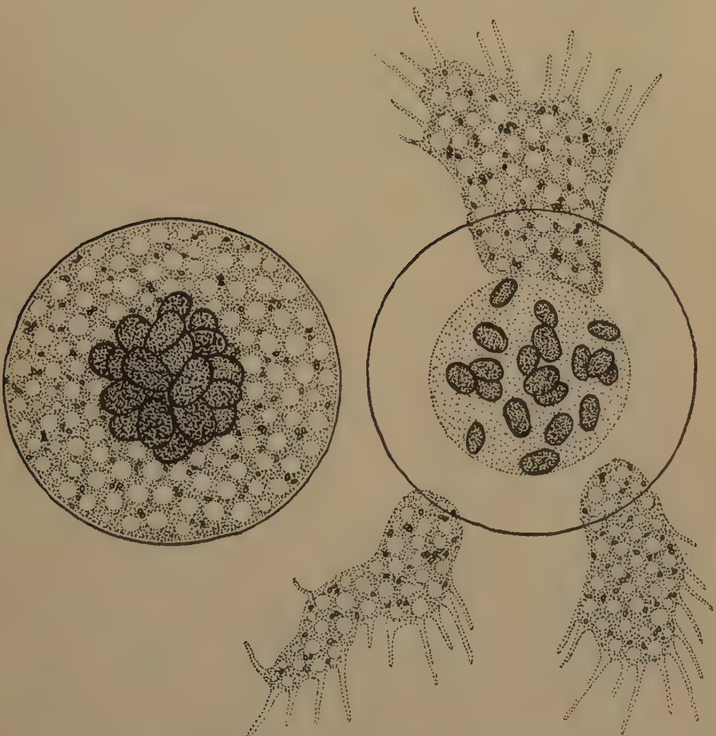

FIG. 29.—*Vampyrella* (*Leptophrys* H. and L.) *elegans*. Left hand figure: an encysted specimen that had eaten about 19 small green plants (*Chlamydomonas*). Right hand figure: same specimen leaving the cyst membrane as three small individuals. A mass of residual material was left behind. ×1000.

cyst wall is broken, the protoplasm streams from the vent in the cyst in a manner that suggests smoke drifting from a chimney. This drifting protoplasm, in the case shown in Figure 31, broke up into four unequal

Fig. 30. — *Vampyrella* (*Leptophrys* H. and L.) *elegans*. Specimen shown in Figure 28 is here shown encysted after it had ingested some diatoms. ×1000.

protoplasmic masses. Each little mass of protoplasm drifted off as a new animal. Thus propagation is effected by this simple protoplasmic creature.

A process somewhat like this takes place when true unicellular animals propagate. However, in a unicellular form, like *Paramecium*, the nucleus must first divide. The smaller part of the nuclear complex, in this case, is the first to show signs of division. Before this has completed its mitotic division the larger element of the nuclear complex has completely divided by amitosis. While these processes have been going on the specimen's peristomal region has become modified and a mid-zonal constriction has arisen. These processes when completed result in the original *Paramecium* being divided near its middle into an anterior part and a posterior part. The anterior zoöid lacks at first a posterior contractile vacuole and other posterior features characteristic of a fully formed *Paramecium;* whereas, the posterior zoöid at first lacks an anterior contractile vacuole and other anterior features characteristic of a fully formed *Paramecium.* Through a process of reorganization and growth each zoöid

eventually comes to be a full-fledged *Paramecium* (Fig. 32).

It is thus seen that when a *Paramecium* begets offspring it becomes the parent of twins but it itself is no more. Further, when grandchildren, by a similar process of dividing or fission, appear it becomes the grandparent of quadruplets but it itself is all the more no more.

FIG. 31.—*Vampyrella* (*Leptophrys* H. and L.) *elegans*. Protoplasm streaming from a cleft in the side of the upper end of the cyst. Before the cyst had been emptied of active protoplasm, four individuals, like the one here shown leaving the cyst, had emerged from the cyst. These four individuals were not of the same size. ×1000.

Thus, in the lowest animals the entity of the individual is wholly sacrificed for the welfare of the race. This makes them stand in sharp contrast with man. In man his integrity as an individual is in no manner lost in propagation; nor is his most complex conduct directed toward propagation. His most complex conduct is rather directed towards the full realization of the individual.

In animals in which the individual has so little emphasis placed upon it, one would not expect to find anything that suggested coöperation between in-

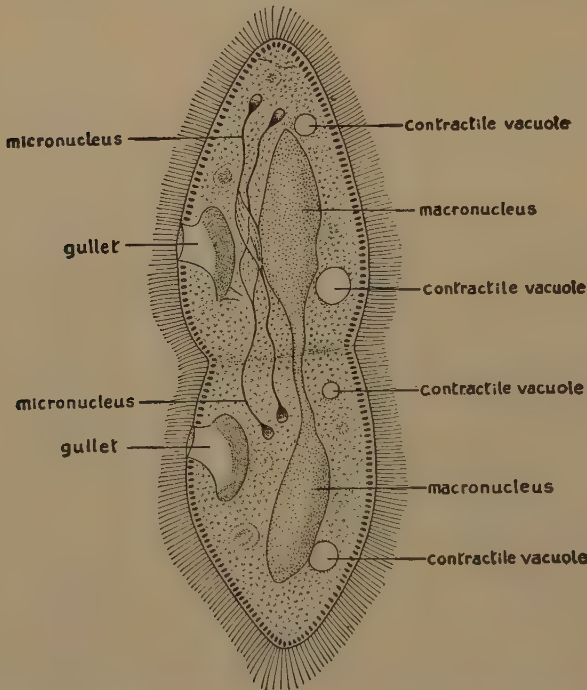

FIG. 32.—"Fission in *Paramecium aurelia*. Note the two micronuclei characteristic of this species. (Redrawn, after Lang" from Newman.)

dividuals and yet such cases have been described for certain unicellular animals.

Some small unicellular animals, that are closely related to *Amœba*, sometimes form "temporary colonies." Delage and Herouard (1896) refer to this type of temporary colony as a *société de consommation.* They indicate that the object of this association is

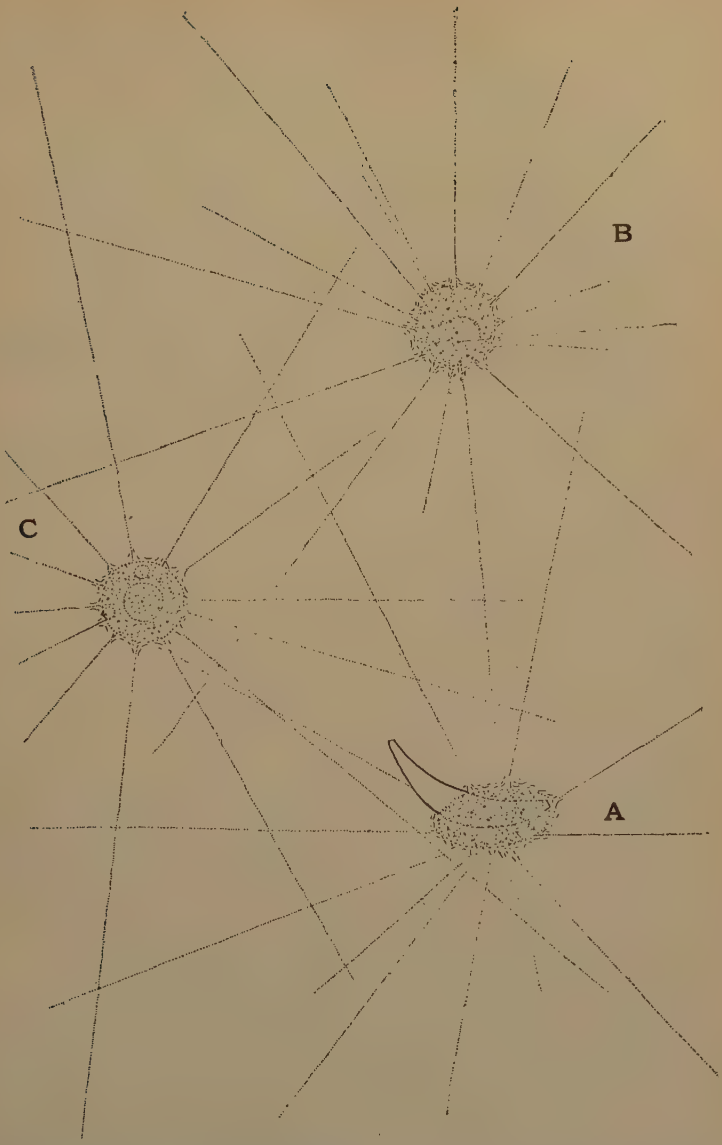

FIG. 33.—Three specimens of *Actinophrys*, *A*, *B*, *C*. Specimen A is shown making an effort to ingest a desmid. ×1000.

to make a larger individual capable of capturing and digesting larger objects of prey. The following observation made by me suggests that this is a veritable *société de consommation*. A specimen of *Actinophrys*, whose pseudopods more or less intersected those of two other individuals was seen to be ingesting a desmid. After this process of ingestion had been advanced to the degree indicated at *A* figure 33, no further ingestion took place. In the meantime specimens *B* and *C* slowly moved towards *A*. Eventually *B* and *C* came in contact with *A* and the bodies of the three animals formed a common protoplasmic mass about the desmid (Fig. 34). Within two hours only some small residual masses were left within the cell-wall of the desmid. It was evident, therefore, that the desmid had been, for the most part, digested. The multiple body of the heliozoa now broke up into three individuals. Each individual then moved away leaving behind an almost empty desmid cell-wall. One cannot observe this process without feeling that this is a clear-cut case of coöperation.

Coöperation between individuals in this case is done with reference to the immediate welfare of the individual concerned; for in this manner they secure a greater amount of food.

Individual protozoa under other conditions coöperate in order that their protoplasm may be reorganized.

Under certain conditions two *Paramecia caudata* will become fixed along their ventral sides. At this time the two individuals are so intimately attached that the cytoplasms of the two cells are confluent. This fusing of two individuals represents the first phase of a series called conjugation. "The micro-

nuclei in each cell first begin to swell by the absorption of fluids from the endoplasm; the chromatin increases

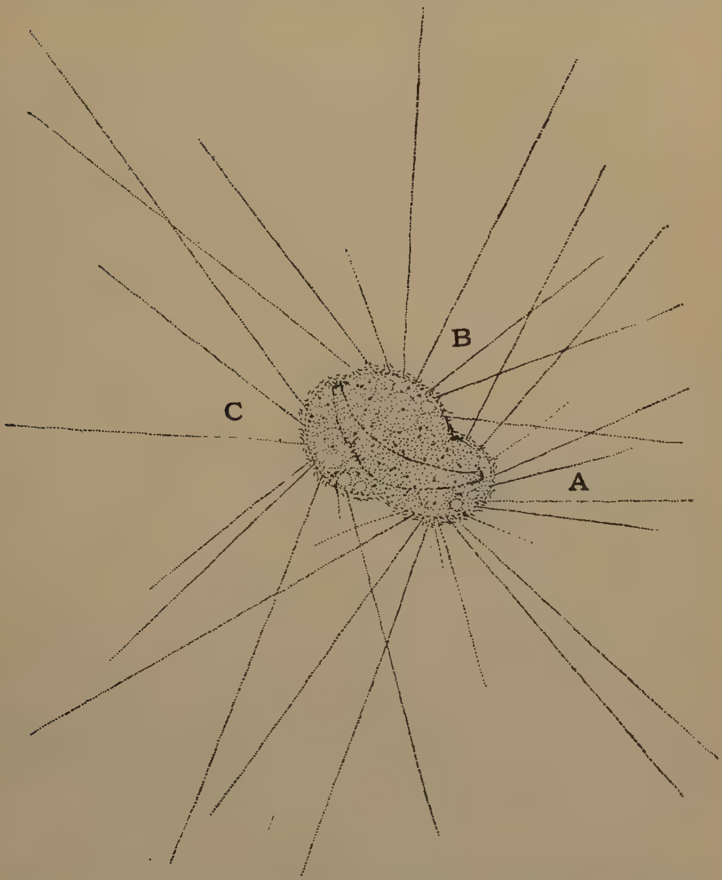

FIG. 34.—Specimens *B* and *C* are shown as having blended with *A* to form a common mass of protoplasm that now quite readily has ingested the desmid. After the digestible parts of the desmid had been absorbed, the three specimens separated. ×1000.

enormously in quantity and becomes drawn out in the form of rods termed chromosomes, too numerous

to count. Each of these chromosomes is then divided into two equal parts, after which the micronuclei divide through the center, each daughter micronuclei receiving one-half the original chromatin. There are now two micronuclei in each cell and all four divide again, forming eight in all or four in each cell. Of

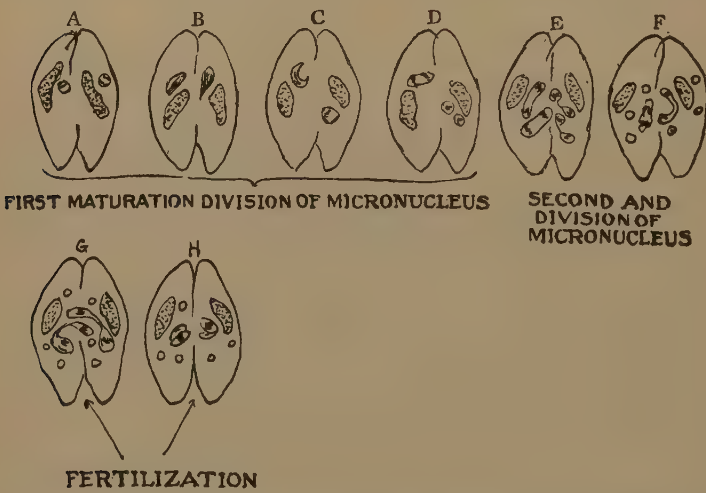

FIG. 35.—Diagrams to show series of changes that take place in conjugation of *Paramecium caudatum*. *A*, two individuals have fused along part of their ventral surfaces. Here each has a big nucleus and a little nucleus. In *B* and *C*, the small nuclei are shown undergoing division. In *D*, one small nucleus has divided, the other has almost done so. In *E* and *F*, four micronuclei (small nuclei) are being formed. In *G* and *H*, three micronuclei in each case are inactive (represented as small open rings), while the fourth is actively dividing. One part of the actively dividing micronucleus of one animal is going over into the other animal in each case in *G*. In *H*, the nuclear exchange has been completed. (From Calkins.)

these four, three degenerate and are absorbed in the endoplasm leaving one micronucleus in each cell. These then divide once again forming what are called pronuclei one of which migrates from its cell into the other cell so that a mutual exchange of pronuclei takes place.

Each wandering pronucleus unites with the stationary pronucleus of the opposite cell and fuses completely with it forming a fertilization nucleus (Fig. 35, *A–H*).

"In the meantime the macronucleus of each cell begins to break itself into pieces and to degenerate and sooner or later it entirely disappears, although this final disappearance does not occur until sometime after the two cells separate and divisions have begun. After separation of the conjugating cells the fertilization nucleus divides three consecutive times thus forming eight micronuclei. Four of these begin to swell, change in character and develop into four new micronuclei. After twenty-four to forty-eight hours the exconjugant divides, two macronuclei and two micronuclei going into each daughter cell. After another twenty-four hours these cells divide again, one micronucleus and one macronucleus going to each daughter cell. With this final division the normal relations of the cell are reorganized and the processes of conjugation are ended, the resulting cells having each one macronucleus and one micronucleus (Fig. 35, *I–P*)." [1] Thus it is seen that two unicellular animals may coöperate in order that they may mutually bring about a reorganization of their body substance. This entire process of conjugation is directed toward an end. A prescience is here evident in the same manner in which it is encountered when one studies oögenesis and spermatogenesis of multicellular animals.

[1] "Biology" Calkins, G. N. (1914). New York, p. 72.

CHAPTER VII

UNICELLULAR ANIMALS LOOKING INTO THE FUTURE

The providence of all animals has to do with the welfare of either the individual or that of its offspring. A bird searches for food in order that it itself may be fed and that its helpless nestlings may not die of starvation. A bird in building a nest is directing its efforts, in an instinctive manner, toward the welfare of its progeny. In a previous chapter I have cited the fact that a bee may in a similar manner make a nest in which to rear its young. There is to be found such reference to the progeny's welfare even among the unicellular animals.

To illustrate this fact, I may take an animal that is closely related to *Amœba*. The structure and habits of this animal suggest very greatly those of *Amœba*. It sends out branches of its unicellular body that resemble much the branches or pseudopodia of *Amœba*. It is sometimes called the "shelled *Amœba*" for it is protected by a shell. This shell is constructed of a number of irregular sand granules (Fig. 36). The particles of sand are cemented together against an organic cuticle that the cell had elaborated. An interesting fact about this shell is that the granules of sand were not collected by the *Difflugia* that uses them in the construction of a shell. These granules were collected by the parent of the *Difflugia*. This is effected

in the following manner. A young *Difflugia* moves about by means of pseudopodia which are thrown out from the mouth of the shell (Fig. 36, *p*). In the early part of its life these pseudopodia select such food as the animal may need and pay no attention to the particles of sand. Later, however, a new impulse takes hold of the little shelled *Amœba* and the pseudopods ingest not only food, but also particles of sand. The sand particles are stored within the cytoplasm of the cell. Here they are retained until the parent cell has put out a protoplasmic bud from the mouth of its shell. After this bud has grown to a certain size the parent cell throws the sand particles into it. The bud now distributes these granules over its surface and cements them together in a somewhat definite manner, so that a specific pattern will be laid down in the masonry of the mouth and neck of the flask, and in species that are characterized by having spines, the spines will be built of the sand granules. In *Difflugia constricta* "a remarkable circumstance is the frequent termination of these spines with a single sharp-pointed and trenchant splinter, as if specially selected for the purpose."[1] After the bud or daughter cell has thus

FIG. 36.—*Difflugia pyriformis.* Specimen shows one large and two short pseudopods thrown out at the mouth. ×300. (Drawn by Dr. Bruce D. Reynolds.)

[1] "Fresh-Water Rhizopods of North America," Joseph Leidy, p. 122.

formed its shell by using the granules of quartz-sand that its parent had collected for it, it breaks away from the parent cell and lives an independent life. In time it

FIG. 37.—*Paulinella chromatophora*. A shelled *Amœba*-like animal. The shell of this animal is composed of six-sided transparent plates. ×1500.

too will select sand granules and perchance the siliceous shell of a diatom for the shell of a daughter cell that it will put off. Thus it comes to pass that no extant

Difflugia has collected the constituent siliceous elements of its own shell—the parent of every living *Difflugia* having collected the sand granules for it.

There are certain other rhizopods that have shells that are constructed of plates of definite shape. In *Paulinella chromatophora* these plates are composed of siliceous material and have six-sided margins (Fig. 37). The glassy shell of this animal is one of the handsomest objects one can see under the microscope. In *Euglypha* the plates are not siliceous but are composed of a chitinoid substance. The plates in this case are oval (Fig. 38). In rhizopods, such as these, the work of shell formation is carried a step beyond that of *Difflugia*. In the latter the units of the shell's wall were collected; in the *Euglypha* and similar animals the plates that form the shell must be elaborated. Leidy (1879) described the shell of *Euglypha* in the following manner: "Hyaline, ovoid, of uniform diameter, or compressed, composed of regular oval or hexagonal plates of chitinoid membrane, arranged in alternating longitudinal series. Mouth terminal, circular or elliptical, with the marginal plates forming a series of minutely serrulate angular points. Shell mostly provided with spines or hairs, though sometimes absent." In *Euglypha*, therefore, there are two kinds of chitinoid elements needed for the formation of the shell's wall: (1) spines, and (2) oval plates (Fig. 38).

Difflugia sets about collecting sand granules and other siliceous small bodies for its offspring when the impulse of propagation properly prompts it; but with *Euglypha* the plates for a shell in which the daughter animal is to live must be elaborated.

In this connection, Leidy in 1879 saw "Living active

individuals of *Euglypha alvealata* . . . containing in the sarcode, in a zone around the position of the nucleus, a multitude of rods, as seen in Figure 1 (my Figure 38). These rod-like bodies are likewise seen occupying nearly the same position, but often irregularly scattered in dead shells, and in these they are recognizable as detached plates, like those composing the shell of the *Euglypha*. What the meaning of this condition is I have been unable to determine." He conjectured, however, that these plates had something to do with propagation. Schewiakoff in 1888 observed that these plates have been formed within the cytoplasm about the nucleus of an *Euglypha* preparatory to the animal's dividing. After these plates have been formed within a specimen, its nucleus shows early phases of nuclear division. As nuclear division or mitosis advances the cell's cytoplasm projects a bud from the mouth of the shell. Into the protruding cytoplasm the internal shell-plates are sent (Fig. 39). As the bud of cytoplasm enlarges, the plates, that had come into it from the parent are arranged about its

FIG. 38.—*Euglypha*. A shelled amœba-like animal. The chitinoid shell-plates are in this case oval. In the fundus of the shell is seen the large spheroidal nucleus. By each side of the nucleus, are newly formed shell-plates, that will be used by the offspring of this specimen in the formation of its shell. (After Leidy.)

surface to form a new shell having a pattern in a general way similar to and a size equal to that of the parent cell (Fig. 39). Food from the cell is sent over into the cytoplasm of the bud (Fig. 39). Nuclear division is carried further (Fig. 39), and eventually completed. After the daughter cytoplasm has received a daughter nucleus the parent and bud separate. Thus a new

Fig. 39.—"Mesomitosis in *Euglypha alveolata*. A–D, different stages in the division of the nucleus and the formation of the second individual. × about 450. (Calkins after Schewiakoff." From Hegner and Taliaferro.)

individual has arisen but the elements of its shell are not products of its own metabolism.

Thus in a closely related group of rhizopods two methods of attaining a similar end have been evolved—one collects the units of which a shell is to be formed, the other elaborates the units of which a shell is to be formed. In this group we have something that reminds us of what has evolved among two closely re-

lated groups of birds. One is familiar with the manner in which the chimney swift tears off a twig as it flies through a tree. As this twig is carried to the chimney the bird lays down about the middle of the twig a belt of mucus. With this mucus the twig will be stuck up against the vertical side of the wall. By the time a second twig has been collected, belted with mucus, and brought to the chimney the mucus of the first has sufficiently dried to support the weight of the two twigs. Thus by the means of mucus secreted from its mouth our American swift can build out a nest from the vertical surface of a chimney by using twigs that it collects. The Asiatic swift, however, has gone further in its evolution when it comes to nest building. It no longer collects material for its nest, but elaborates an abundant supply of mucus. This mucus is discharged from the mouth in a thread that is shaped into a nest. After the mucus has dried the nest has the texture and general appearance of that of a shredded wheat biscuit. It is these nests composed of dried mucus, that the Asiatics eat. Here, as in the rhizopods, we have two methods of attaining an end—one through collecting materials, the other through elaborating materials.

While there may thus be a close contrast between the shell building of two rhizopods and the nest building of two swifts, a sharp contrast appears when we consider the phylogeny of the rhizopods and that of the birds. In the ancestral history of birds there must have been a period when nest building had not been developed. In time by some method nest building became more and more established. But in all cases each bird made its own nest. It is at this point that a comparison may be made. For as we look back over

the hypothetical ancestral history of *Difflugia* and *Euglypha* we must recognize a period wherein shell-building did not take place. Eventually some naked amœba-like individuals must have taken to forming shells for themselves. It may be that this shell-forming habit arose as a modification of the tendency of a parent cell to encyst, or what not. At all events the first shell-forming individuals probably must have made shells for themselves only. How has it come about

FIG. 40.—"*Microgromia socialis* Hert. [HERTWIG.] Division takes place within the shell, and one of the daughter-individuals migrates, forming a new shell." (From Calkins.)

that unicellular animals, that must have at first made their own shells, now have their shells made for them as the nestlings' nests have been made for them? This fact runs counter, in other words, to the "important rule . . . that, at whatever period of life a peculiarity first appears it tends to reappear in the offspring at a corresponding age, though sometimes earlier." [1]

All this too has transpired in the face of the fact that it is not necessary from the standpoint of shelled rhizopods that the daughter be supplied with a shell before leaving the parent. *Microgromia socialis* sends

[1] "The Origin of Species," Charles Darwin, Cpt. I, p. 12.

its daughter off as a naked amœboid creature (Fig. 40).

A living thing's prescience is conspicuous while it is carrying out the phenomena of propagation. In plants all sorts of contrivances are formed in order that currents in the air or in the water or animal visitors may be made to serve the ends of propagation. We need, therefore, but to be reminded of the prescience attending propagation of plants and animals to recognize its universal presence.

When it comes to the conduct of the individual unicellular animal, prescience at first sight appears to be less conspicuous. But the future is involved in the daily conduct of the unicellular animal just as it is in its propagation. A few examples will make this evident.

The slipper animalcule, *Paramecium*, elaborates short stout rods that lie within the ectoplasm. These rods are called trichocysts. They are generally considered to have been elaborated with reference to defense. The best evidence that we have of them being actually used as defensive structures has been given by Mast. His observations suggest that they may be elaborated with reference to *Paramecium's* worst enemy—*Didinium*. *Didinium* attacks a *Paramecium* by means of its peristome, which can be thrown out as an elongated tubular proboscis. When *Didinium* succeeds in fixing its elongated cytopharynx to a *Paramecium*, it is able usually to suck much of the *Paramecium's* body into its own. When a *Didinium* has thus attacked a *Paramecium*, the latter discharges its trichocysts, which form a great tangled mass about its body (Fig. 41). This discharge of trichocysts in the case of the largest *Paramecia*, forms such a dense mass

that the *Didinium* is pushed free from the *Paramecium* and the latter thus escapes death.

Another instance in which trichocysts appear to have been developed with reference to a certain animal is seen in the remarkable ciliate, *Actinobolus radians*. Here we have trichocysts not primarily as defensive but as offensive structures; for *Actinobolus radians* "combines the selection of food with the offensive use

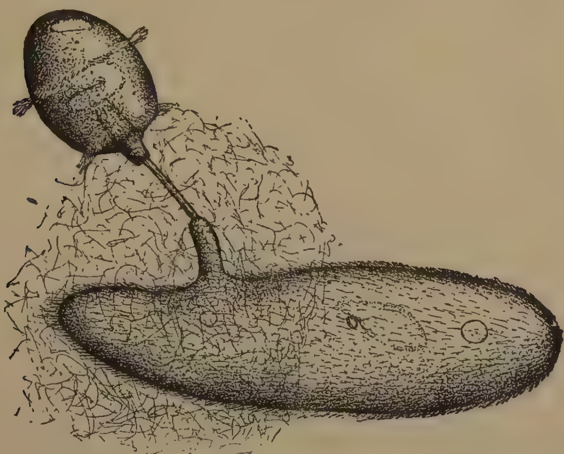

FIG. 41. "*Paramœcium* defending itself from an attack by a Protozoön *Didinium*. The trichocysts are discharged and mechanically force the enemy away. (From Mast in *Biol. Bul.*)" (From Hegner.)

of trichocysts. This remarkable organism possesses a coating of cilia and protractile tentacles, which may be elongated to a length equal to three times the body-diameter, or withdrawn completely into the body (Fig. 42). The ends of the tentacles are loaded with trichocysts (Entz, '83). When at rest the mouth is directed downward, and the tentacles are stretched out in all directions, forming a minute forest of plasmic processes, amongst which smaller ciliates, such as

Urocentrum, *Gastrostyle*, etc., or flagellates of all kinds, may become entangled without injury to themselves and without disturbing the *Actinobolus* or drawing out the fatal darts. When, however, an *Halteria*

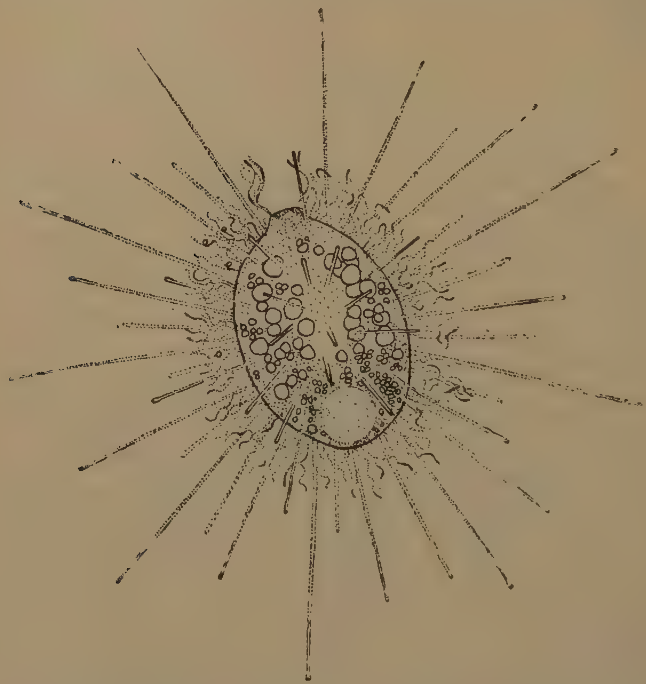

FIG. 42.—*Actinobolus radians*. The undulating structures at the surface are cilia or organs of locomotion. The rod-like, radiating structures are the protractile tentacles. Upon the ends of these tentacles trichocysts ("stinging threads") are elaborated. ×1000.

grandinella, with its quick and jerky movements approaches the spot, the carnivore is not so peaceful. The trichocysts are discharged with unerring aim, and the *Halteria* whirls around in a vigorous, but vain, effort to escape, then becomes quiet with cilia

outstretched, perfectly paralyzed. The tentacle, with its prey fast attached, is then slowly contracted until the victim is brought to the body, where, by action of the cilia, it is gradually worked around to the mouth and swallowed with one gulp. Within the short time of twenty minutes, I have seen an *Actinobolus* thus capture and swallow no less than ten *Halteria*."[1]

But even in the face of so much evidence of this kind, biologists have been reticent and have hesitated to credit the trichocysts with having a defensive or offensive function. Jennings ('06) wrote trichocysts "are usually supposed to be weapons of defense, but whether they really serve for defense seems questionable."[2]

However, Visscher ('23) has studied the effect of the trichocysts of *Dileptus gigas* (Figs. 43, and 44, *t*) upon *Paramecium bursaria*, *Stentor cœruleus*, *Paramecium aurelia*, *Spirostomum* and upon "various other organisms." "These observations seem

[1] "The Protozoa," Gary N. Calkins, New York, 1901, p. 50.
[2] "The Behavior of the Lower Organisms," H. S. Jennings, 1906, New York, p. 91.

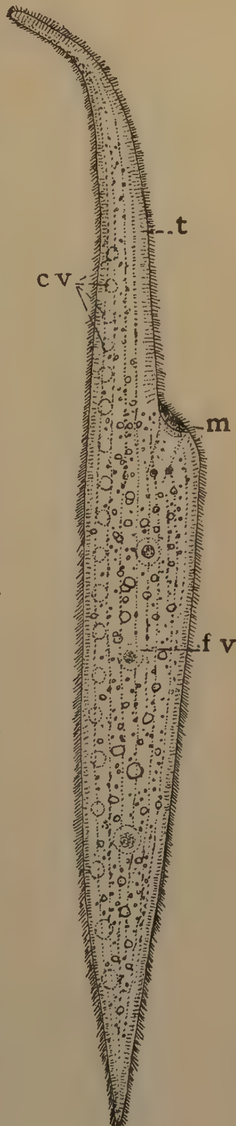

FIG. 43. — *Dileptus gigas*. *t*, trichocysts ("stinging threads"); *cv*, contractile vacuoles; *m*, mouth with supporting rods shown in pharynx; *fv*, food vacuoles. ×300.

to show conclusively that the trichocysts discharged by *Dileptus gigas*, first temporarily paralyze the prey, then produce a period of increased activity in the nature of a negative reaction on the part of the prey, and simultaneously effect a cytolytic action at the point of contact."[1] He concluded that it, therefore, "captures its food by means of trichocysts which either paralyze the prey . . . or bring about cytolysis of all or part of the protoplasm of the prey."[2] He also verifies Mast's observation that the trichocysts of *Paramecium* serve as a protection against an attacking protozoön.

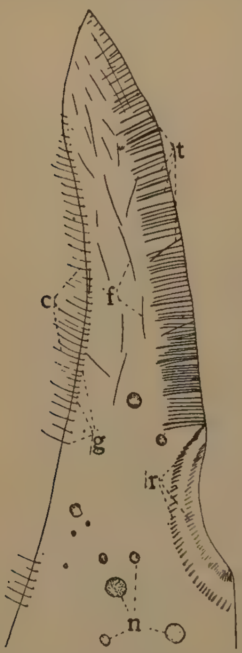

FIG. 44.—A section through the contracted proboscis of *Dileptus gigas*. Drawn with a camera lucida. *t*, trichocysts; *c*, cilia; *f*, contractile fibrillæ; *g*, basal granules of cilia; *n*, nuclear bodies; *r*, pharyngeal rods. (After Visscher.)

Hence it appears that just as men engaged in making weapons do not work to meet merely the needs of the present time, so unicellular animals elaborate trichocysts and perhaps nematocysts not by way of reactions to a set of isolated present conditions, but work with reference to meeting some future condition or contingency.

Even in the matter of feeding the presence or absence of a contingency becomes a modifying factor in an unicellular animal's behavior. This can be seen in the food reactions of *Amœba* and *Pelomyxa*. And

[1] Visscher, J. Paul (1923), "Feeding Reactions in the Ciliate Dileptus Gigas," Biological Bulletin, Vol. 45, p. 138, 1923.

[2] l. c., p. 141.

this, despite the fact that so recent as 1905 Loeb says "As a criterion for 'living matter' we might use the irritability or spontaneity. But as the 'spontaneity' of living matter is in its simplest form (in *Amœbæ*) apparently not different from the physical phenomenon of spreading, for this criterion the limits of divisibility of living matter coincide with the limits of purely physical phenomena." [1] The variability, and the qualitative and regulatory characteristics of the food-reactions of *Amœba* and *Pelomyxa* cause me to feel that Loeb's coincidence is not so close as he would have us believe.

Amœba and *Pelomyxa* are omniverous. They feed upon both nonmotile and motile plants and animals. It thus comes about that these animals react to objects that stimulate them in many ways. Some plants are nonmotile and give off oxygen; some animals are nonmotile and give off carbon dioxide. Some plants, however, may be motile while some animals are nonmotile. The most significant difference met with in the objects upon which *Amœba* and *Pelomyxa* prey is that one group is nonmotile and does not present the contingency of escape; while the other group is motile and presents a contingency of escape.

The presence or absence of this contingency of escape becomes a factor in shaping the reaction of these forms to an object of prey, just as man's reaction to an object, that he is about to lay hold of, is shaped by the presence or absence of the contingency of escape. For example, if a man is about to lay hold of a book he takes it up directly. There is no danger of the book escaping; so without any precaution the book is

[1] "Studies in General Physiology," by J. Loeb, Chicago, p. 321.

FIG. 45.—*Pelomyxa* reacting to a nonmotile, spherical green plant. In this reaction an intimately fitting cup was formed about the plant. *a*, the margin of the cup soon after its inception; *b*, the margin of the cup later; *c*, *c′* the cup's margins about to fuse to completely enclose the green plant. ×100. (After Kepner and Edwards.)

taken up. If, however, a man is about to take up a Guinea pig, that is not any too well tamed, he goes about this effort in an indirect manner. The situation here presents a contingency of escape; so he approaches the Guinea pig in such an indirect manner as to cut off its possible paths of escape. So likewise *Amœba* and *Pelomyxa* go directly for an object that presents no contingency of escape; whereas, they go indirectly, in a great variety of ways after objects that present the contingency of escape.

The following examples have been selected as types of reactions to nonmotile objects.

"A *Pelomyxa* moving in the direction of a green *Eremosphæra* encountered the spherical alga eccentrically so as to turn it counter-clock-wise (as seen under the compound microscope) through about ten revolutions. The *Eremosphæra* was not moved farther than this. The tip of the *Pelomyxa's* pseudopod next expanded to fit intimately the contour of the algal cell. This

process continued until either a cup or an overarching of the rhizopod's protoplasm had advanced to the contour *a*—figure 1 (Fig. 45). The margin *a* then advanced to contour *b* and beyond to margins *c* and *c'* which had fused, bringing the spherical green cell within a closely fitting food vacuole." (Fig. 45).[1]

Jennings ('04) observed an *Amœba proteus* attempting to lay hold of a spherical plant cell. He gives his observation in the following words: "An *Amœba proteus* was creeping toward an encysted *Euglena*. The latter was perfectly spherical and very easily moved, so that when the anterior edge of the *Amœba* came in contact with it the cyst merely moved forward a little and slipped to one side (the left). The *Amœba* thereupon altered its course so as to follow the cyst (Fig. 46). The cyst was shoved forward again and again, a little to the left; the *Amœba* continued to follow. This continued until the two had traversed about one fourth the circumference of a circle; then (at 3) the cyst, when pushed forward, rolled to the left quite out of contact with the *Amœba*. The latter then continued forward with the broad anterior edge in a direction which would have taken it past the cyst. But a small pseudopodium on its left came in contact with the cyst. The *Amœba* thereupon turned again and followed the rolling cyst. At times it sent out two pseudopodia, one on each side of the cyst, (as at 4), as if trying to inclose the latter, but the ball-like cyst rolled so easily that this did not succeed. At other times a single very long, slender pesudopodium was sent out, only the tip of which remained in contact

[1] Kepner and Edwards ('17) "Food Reactions of *Pelomyxa*," Journal of Experimental Zoölogy, Vol. 24, pp. 383–4.

with the cyst (5). Then the body of the *Amœba* was brought up from the rear and the cyst pushed farther. This continued until the rolling cyst and following *Amœba* had described almost a complete circle, returning nearly to the point where the *Amœba* had first come in contact with the cyst. At this point, owing

FIG. 46.—"*Amœba* following a rolling *Euglena* cyst that was pushed ahead of the *Amœba* as the latter tried to ingest it. 1–9 show successive positions of *Amœba* and the cyst." (After Jennings.)

to the form of the anterior end of the *Amœba* (7) the cyst rolled to the right instead of to the left as it was pushed forward. The *Amœba* followed (8, 9). This new path was continued for two or three times the length of the *Amœba*. The direction in which the ball was rolling would soon have brought it against an impediment, and I thought it possible that the *Amœba* might succeed in ingesting it after all. But at this point one of those troublesome disturbers of the peace

in microscopic work, a ciliate infusorian, came near and whisked the ball away in its ciliary current."[1]

Amœba sometimes ingests filamentous plants and breaks the filaments into short rods within its body.

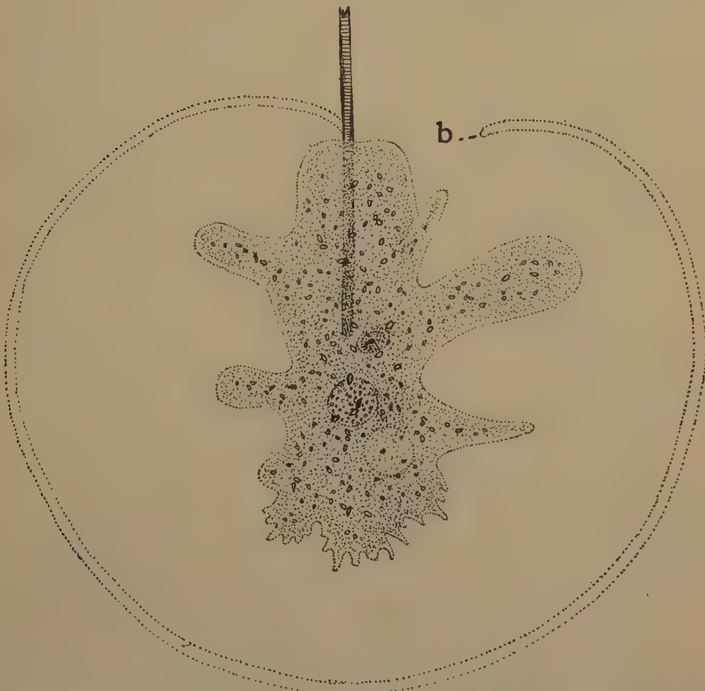

FIG. 47.—A very long, quiet *Oscillatoria* filament was partly ingested, when the filament was bent to contour *b* with the end of a glass rod after which it slipped from the rod. This process was repeated 20 times before the *Amœba* released the plant filament. ×100. (After Kepner and Whitlock.)

Some interesting observations, showing that an *Amœba*, in laying hold of a nonmotile object embraces it tightly, have been made in this laboratory. My colleague, Dr. I. F. Lewis, "was given an *Amœba* that

[1] H. S. Jennings (1904), "The Behavior of Lower Organisms," Carnegie Institute, Washington, pp. 196–7.

had ingested an end of a very long filament, indicated as broken off in Figure 47. He took a fine glass rod and bent the plant to contour *b*" (Fig. 47), at which point the tension of the alga caused it to spring back as a straight rod. "'Twenty big bends, some like this, others different, were made as the *Amœba* gradually lost its hold.'"[1]

A *Pelomyxa* "was traveling along in the direction

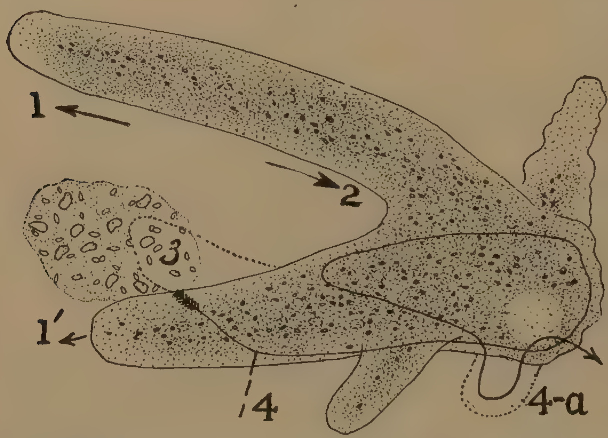

FIG. 48.—A *Pelomyxa* reacting to a mass of bacterial glea. After pseudopod, *1'*, had come in contact with the glea, pseudopod *1* reversed its course and flowed back in direction of arrow 2. In the meantime pseudopod, *1'*, sent out pseudopod, *3*. The reaction as further carried out is shown in Figure 49. ×100. (After Kepner and Edwards.)

of the two pseudopods *1* and *1'* as indicated by the arrows (Fig. 48). Pseudopod *1* came in contact with a rounded bacterial mass within which were two kinds of ciliates. The longer type of ciliate was about the size of *Loxocephalus granulosus*, but for these we had no time to determine the genera and species. When

[1] Kepner and Whitlock (1921), "Food-Reactions of Pelomyxa," Journal of Experimental Zoölogy, Vol. 32, p. 399.

this contact with the mass of bacteria and of ciliates was made, a reversal of the course of pseudopod *1* occurred as indicated by arrow *2* and pseudopod *3* grew out over (above) the bacterial glea and in this way exerted enough pressure to cause one of the large ciliates to leave the glea and swim beneath the body of *Pelomyxa* as indicated by the line *4*. At *4-a* it had escaped

FIG. 49—*1'* and *3* of Figure 48 are now shown as having grown about (as *5* and *5'*) the bacterial glea so as to have divided it, the smaller mass being rejected. Next pseudopods *5* and *5'* have grown and surrounded all but a small portion of the larger part of the glea. In this case pseudopods *5* and *5'* have grown to become *6* and *6'*. ×100. (After Kepner and Edwards.)

and a curtain of protoplasm was thrown above it, driving it back beneath the body proper of *Pelomyxa*, from which it finally escaped along the path leading to the head-end of line *4*. In the meantime pseudopods *1* and *3* advanced around the sides and over the bacterial glea causing it to be stretched into a bilobed mass, the smaller lobe being squeezed out of the constricting region between the bases of the pseudopods. This smaller mass, containing two of the larger and nine of the smaller ciliates, was eventually completely constricted and rejected. The larger mass of the glea

was for the most part ingested by the means of the pseudopods *5* and *5′* (Fig. 49) encircling about it as indicated by the contours *6* and *6′*. As the tips of *6* and *6′* approached and fused, a minute mass of glea containing one large and two small ciliates was constricted. Two portions of the original ciliate-containing glea were thus at 11:20 a. m. rejected and the third and largest mass was ingested. After this largest mass had been ingested it was broken into small spheroidal masses, each of which was now contained in a separate food vacuole. At 12:15 p. m. the animal was just leaving the rejected balls of bacterial glea and showed many food vacuoles within which were active ciliates."[1]

Fig. 50.—An *Amœba*, advancing along the path indicated by the arrow, ingesting part of a nonmotile bacterial glea by constricting it with pseudopods *a* and *b*. ×200. (After Kepner and Whitlock.)

"February 16, 1918, Dr. R. D. Mackay observed an *Amœba* glide over a glea. As it was about to leave the glea, two embracing pseudopods were sent out about the bacterial mass.

[1] Kepner and Edwards, l. c., pp. 384–5.

These pseudopods lay close up to the sides of the rounded mass and eventually constricted a small portion from the glea as the enclosing pseudopods began to converge (Fig. 50 *a* and *b*)." [1]

Thus *Amœba* and *Pelomyxa*, in reacting to non-motile objects of prey, intimately embrace their victims.

The reactions are quite different when motile objects, presenting the contingency of escape, are being attacked. For example when Jennings ('04) found an *Amœba* trying to ingest a motile fragment of another *Amœba*, he observed that at first it had intimately laid hold of the ball of cytoplasm that had not yet detached itself from the parent cell; but after this fragment had become motile and had escaped the reaction was different. He describes the reactions as follows: "I had attempted to cut an *Amœba* in two with the tip of a glass rod, in the manner described later. The posterior third of the *Amœba*, in the form of a wrinkled ball, remained attached to the body only by a slender cord, the remains of the ectosarc. The *Amœba* began to creep away, dragging with it the ball. I will call this *Amœba a*, while the ball will be designated *b*. A larger *Amœba* (*c*) approached, moving at right angles to the path of the first *Amœba;* its course accidentally brought it in contact with the ball *b*, which was dragging past its front. *Amœba c* thereupon turned, followed *Amœba a*, and began to engulf the ball *b*. A large cavity was formed in the anterior end of *Amœba c*, reaching back nearly or quite to its middle, and much more than sufficient to contain the ball *b*. *Amœba a* now turned into a new path; *Amœba c* fol-

[1] Kepner and Whitlock, l. c., p. 400.

lowed (Fig. 51 at 4). After the pursuit had lasted for some time the ball *b* had become completely enveloped by *Amœba c;* the cord connecting it with *Amœba a* broke, and the latter went on its way (at 5) and disappears from our account. Now the anterior opening of the cavity in *Amœba c* became partly closed, leaving a slender canal (5). The ball *b* was thus completely inclosed, together with a quantity of water. There was no union or adhesion of the protoplasm of *b* and *c;* on the contrary (as the sequel will show clearly) both remained quite separate, *c* merely inclosing *b*.

"Now the large *Amœba c* stopped, then began to move in another direction (Fig. 51, *5–6*, carrying with it its meal. But the meal, the ball *b*, now began to show signs of life, sent out pseudopodia, and, indeed, became very active. We shall henceforth, therefore, speak of it as *Amœba b*. It began to creep out through the still open canal, sending forth its pseudopodia to the outside (Fig. 51, 7). Thereupon *Amœba c* sent forth its pseudopodia in the same direction, and after creeping in that direction several times its own length, again completely inclosed *b* (7–8). The latter again partly escaped (*9*), and was again engulfed completely (10). *Amœba c* now started again in the opposite direction (11), whereupon *Amœba b*, by a few rapid movements, escaped entirely from the posterior end of *c*, and was free, being completely separated from *c* (11–12). Thereupon *c* reversed its course (12), crept up to *b*, engulfed it completely again (13), and started away. *Amœba b* now contracted into a ball, its protoplasm clearly set off from the protoplasm of its captor, and remained quiet for a time. Apparently the drama was over. *Amœba c* went on its way for about five min-

Fig. 51.—"Pursuit, capture, and ingestion of one *Amœba* by another; escape of the captured *Amœba* and its recapture; final escape." Observe that at *1* the pursuing *Amœba* is intimately applying its body about the fragment *b* of the *Amœba a*, but that, after it had had more experience with this fragment, it always formed a food cup about it as at *2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15*. (From Jennings.)

utes, without any sign of life in *b*. In the movements of the *Amœba c* the ball *b* gradually became transferred to the posterior end of *c*, until finally there was only a thin layer between *b* and the water. Now *b* began to move again, sent out pseudopodia to the outside through the thin wall, and then passed bodily out into the water (14). This time *Amœba c* did not return and capture *b*." [1] By comparing *1* with *2* in Figure 51 it will be seen that the *Amœba* reacted to the spherical fragment of an *Amœba* that had not as yet escaped from it as Jennings's *Amœba* had reacted to an encysted *Euglena* (see Fig. 46); but soon after the fragment had moved from it, there was no longer a tight embrace of the fragment of *Amœba* that it tried to ingest.

The form of the *Amœba's* body seems to be a factor in shaping the details of a reaction toward an object that is liable to escape.

"We have seen three instances of a *Chilomonas paramecium* and one instance of a diatom entering the narrow angle between two pseudopodia and coming in contact with the ectoplasm at the apex of this angle. In all these cases the reactions were analogous. The specimen represented in Fig. 52 had a *Chilomonas paramecium* swim into the narrow angle between two pseudopodia and which made repeated contacts at *a*. The response to this stimulus at *a* resulted in the formation of pseudopodia behind the *Chilomonas* at *b* and *c*." [2]

"In contrast with the last observations is one made upon a specimen that had two widely diverging pseudopodia. The general movement of the body was in

[1] Jennings, H. S., l. c., pp. 200–202.
[2] Kepner and Taliaferro, Biological Bulletin, vol. 24, p. 415.

the larger pseudopodium. A *Chilomonas paramecium* came in contact with the middle of the mesial surface of the smaller pseudopodium. The flagellate made a

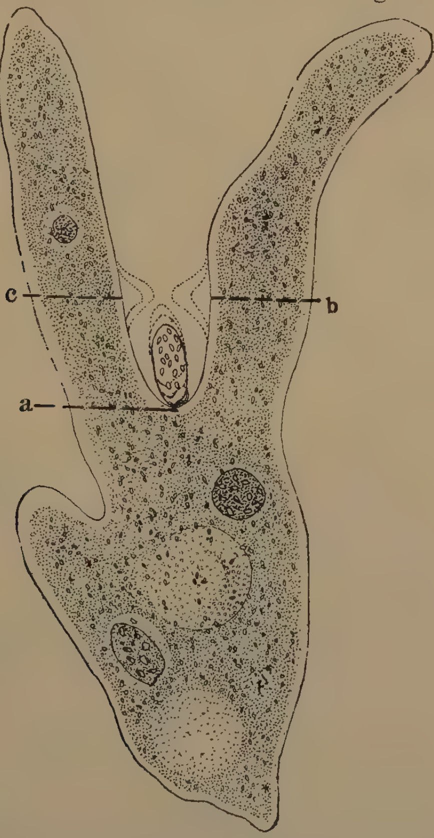

FIG. 52.—*Chilomonas*, by advancing and retreating and again advancing, made three contacts with *Amœba* at *a*. "The response of the *Amœba* to these contacts was not at the point stimulated but at points *b* and *c*. From these points secondary pseudopodia grew towards each other, as indicated by the dotted lines. ×333." (From Kepner and Taliaferro.)

single impact at this point and lay in contact with the ectoplasm. In response to this contact the *Amœba*

proteus sent out a third protoplasmic process from the apex of the angle between the first two pseudopodia (Fig. 53, *a*), thus placing the object of prey in a narrow angle between two pseudopodia. Before the end of pseudopodium *a* reached the level of the end of its neighbor it changed its course so as to flow behind the *Chilomonas*. At the same time the original pseudopodium sent out a secondary one (Fig. 53, *b*) below its apex to meet the other inclosing pseudopodium. In

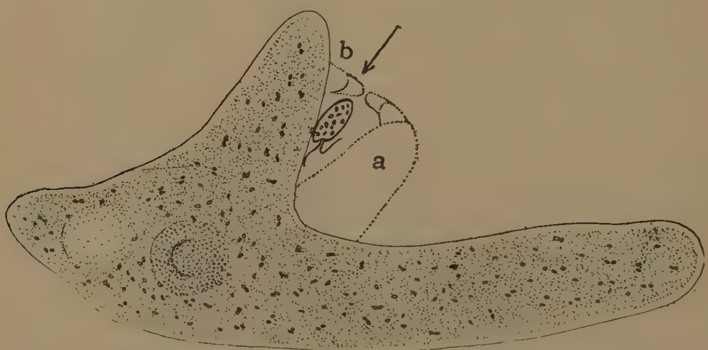

FIG. 53.—A *Chilomonas* entered the wide angle between the two large pseudopods in the direction indicated by the arrow. The two animals lay now in contact. In response to this contact a small secondary pseudopodium, *b*, arose behind the prey and a large pseudopodium, *a*, arose from the fundus of the interpseudopodial angle. ×333. (From Kepner and Taliaferro.)

this way the *Chilomonas* was inclosed in a food vacuole of about the usual size." [1]

When a broad anterior region of *Pelomyxa's* body encounters motile objects the reactions may become quite involved. This is seen in the following reaction: "We found a *Paramecium caudatum* (Fig. 54–*1*), 'tickling' the 'anterior' end repeatedly by darting against the *Pelomyxa* and then retreating and again

[1] Kepner and Taliaferro, l. c., p. 415.

advancing to encounter the *Pelomyxa* at another part of its greatly expanded end. While we waited for a response to these recurring contacts, a *Loxocephalus* came to play repeatedly against the anterior end at the position *3* in figure 54. In response to these two sets of stimuli, pseudopods *a* and *a′* arose. The second one of us was now called in to collaborate in this observation. Pseudopods *a* and *a′* advanced to contours

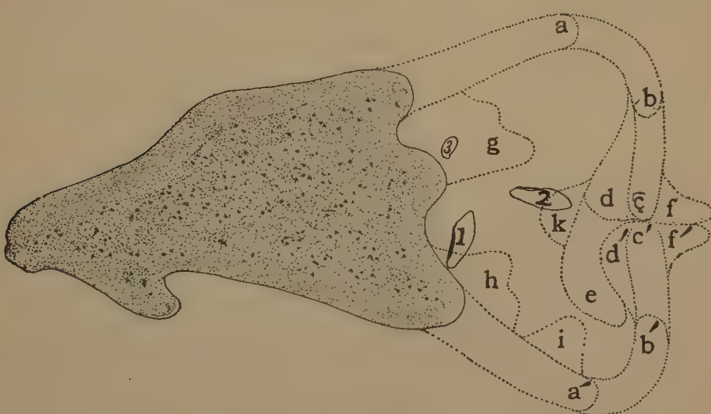

FIG. 54.—*Pelomyxa* reacting to two *Paramecia* and a smaller ciliate. See text for description of this complex reaction. ×100. (From Kepner and Edwards.)

b and *b′*. About this time a second *Paramecium caudatum* entered the breach and lay in the partly inclosed space. Next *b* and *b′* met at *c* and *c′*; but there was no fusion of the ectoplasm of *c* and *c′*. The inner margins widened to form upward-projecting films of protoplasm *d* and *d′*; film *d* elongated and passed down by the side of *d′* to widen the overarching protoplasm along contour *e*. The ciliates now began to show signs of uneasiness and darted to and fro hitting the edges of the inclosing pseudopods which could be clearly

seen to deflect the ciliates toward the surface film of the hanging drop of water.

"Next there appeared two outer pseudopods *f* and *f′*, which at no time became active. Finally *g*, *h*, *i*, as broad bands of overarching cytoplasm, came up over the space inclosing the three ciliates and eventually fused with the inner margins of *d* and *e* to complete

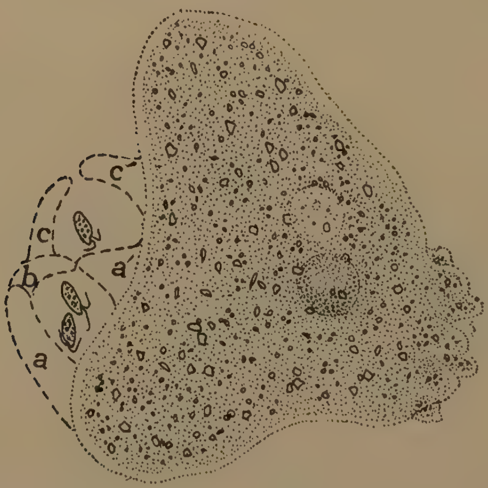

FIG. 55.—As an *Amœba* was sending out pseudopods, *a–b* and *a′*, about two *Chilomonases*, a third *Chilomonas* came to lie along the outer margin of *a′*, whereupon, *b* gave off *c* and the body-proper gave off *c′*. In this manner all the flagellates were captured. ×200. (From Kepner and Whitlock.)

the inclosing vault of the trap—the surface film of the hanging drop forming the floor. Next the space was divided, *k* and other parts of protoplasm forming a constriction. In one secondary space a *Paramecium* was enveloped and in the other the second *Paramecium* and the *Loxocephalus* were inclosed. These secondary spaces were finally reduced greatly and in the end

each *Paramecium* was divided into three parts—each part entering a food-vacuole." [1]

The broad advancing region of an *Amœba's* body will react in a similar manner. In Figure 55 "two *Chilomonases* were being surrounded by pseudopods *a* and *a′*. When *a* had grown to encounter *b*, a third *Chilomonas* came up by the side of *a′*. In reacting to this third

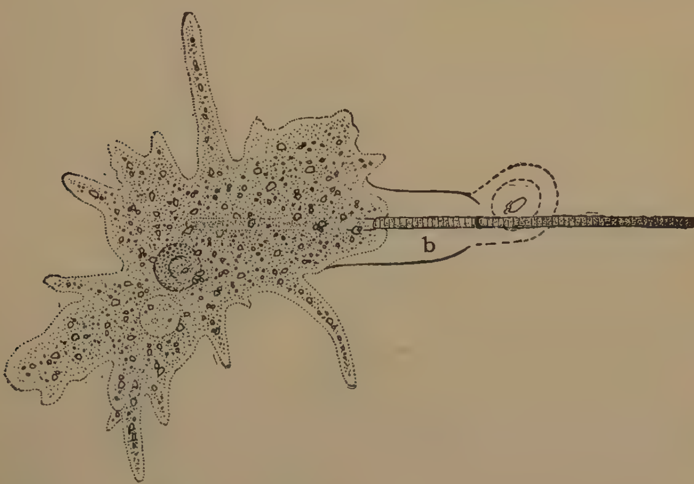

FIG. 56.—An *Amœba* reacting synchronously to an object, that cannot escape (a rod-like plant), and to a small bi-flagellated animal, that has the power to escape. The one is being tightly embraced, whereas the other is having a cylindrical wall of protoplasm dropped around it at a distance that has not disturbed it. ×200. (From Kepner and Whitlock.)

Chilomonas, the body proper threw out pseudopod *c′*, while pseudopod *b* sent out *c* to meet *c′*. In this manner all three flagellates were captured." [2]

Not only does the form of the animal's body become a factor in shaping a reaction toward an animal that

[1] Kepner and Edwards, l. c., pp. 388–389.
[2] Kepner and Whitlock, l. c., p. 402.

is liable to escape, but conditions within the surrounding media become modifying factors.

In deep water, for example, a curtain of cytoplasm may be dropped down about a victim or a cup may form beneath the victim. "While an *Amœba* was ingesting a quiet filament of *Oscillatoria*, a *Chilomonas* came to lie beneath the filament at a position indicated in Figure 56. The *Chilomonas* was lying beneath the

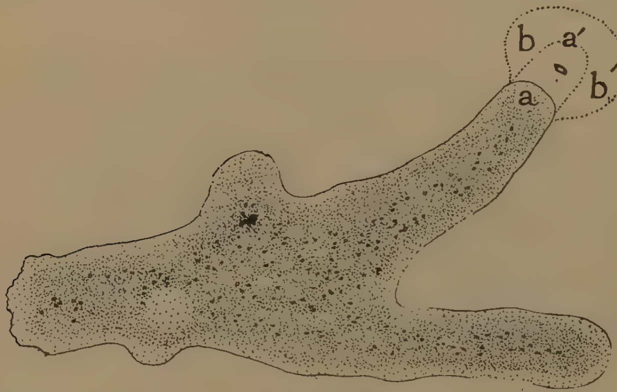

FIG. 57.—*Pelomyxa* reacting to a *Chilomonas* that lies above it. In this instance a wide cup was formed about the prey from beneath. ×100. (From Kepner and Edwards.)

plane in which the filament of *Oscillatoria* lay. The *Amœba* advanced about the plant until pseudopod *b* was formed. This pseudopod then sent out an encircling wall of cytoplasm about the *Chilomonas* and then overarched it with an ectoplasmic film. The space within which the *Chilomonas* was thus taken was next divided into a larger and a smaller vacuole, the prey being in the smaller vacuole. The *Chilomonas* was not disturbed until it was thus inclosed within the smaller vacuole."[1]

[1] Kepner and Whitlock, l. c., pp. 405–406.

When a pseudopod of *Pelomyxa* moves beneath a *Chilomonas*, it travels a certain distance as, for example, to "point *a*, Figure 57. The pseudopod *a* now expanded beneath the *Chilomonas* to the contour *b–b′*. A cup was evidently formed about the flagellate, though the details of the cup's formation could not be seen; for eventually the *Chilomonas* began struggling within a

FIG. 58.—An *Amœba* capturing two *Chilomonases* that lie in water so shallow that only ectoplasm can be sent out into it about the objects of prey; *A*, a swarm of dancing bacteria. ×200. (From Kepner and Whitlock.)

space about as large as was the diameter of pseudopod *a*. The space became more and more reduced as the *Pelomyxa* flowed on, until eventually the *Chilomonas* lay quiet within a small vacuole at the posterior end of the animal."[1]

When the prey lie in shallow water only the ectoplasm is concerned in capturing the victims. "In one instance we observed an *Amœba* approach two *Chilomonases* in the shallow margin of a hanging drop. In

[1] Kepner and Edwards, l. c., p. 390.

this case ectoplasmic pseudopods *a* and *a'* were sent out about the *Chilomonases* (Fig. 58). As *a* grew down to contour *b*, an overarching layer of ectoplasm, *c*, was formed above the prey. The internal margins thus formed eventually fused as *b* grew down to divide the inclosed space into two food vacuoles. The animal then moved out into deeper water. The unusual feature of this reaction is not that the overarching

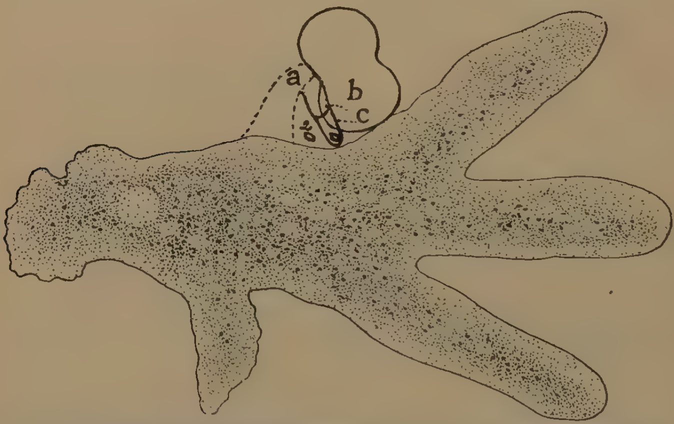

FIG. 59.—"*Pelomyxa* capturing a *Chilomonas* that lies in the angle between its body and a desmid. Pseudopod *a*, when it came in contact with the desmid, was deflected to grow to *b* and then to *c*. ×100." (From Kepner and Edwards.)

protoplasm is ectoplasmic, for that and the underhanging wall of the forming food vacuole are usually ectoplasmic. The unusual feature is the fact that the ectoplasm formed all sides of the forming food vacuoles. These vacuoles were thrown into the endoplasm when the animal moved out into the deeper regions of the drop after capturing the two flagellates."[1]

Even solid bodies may become factors in shaping the reactions of *Amœba* and *Pelomyxa* to motile food.

[1] Kepner and Whitlock, l. c., pp. 401–402.

For example, "A *Chilomonas* was playing in the bay formed between one side of *Pelomyxa's* body and a desmid that lay in contact with the rhizopod. In response to this but one pseudopod was sent out which advanced to make a contact with the desmid (*a*, Fig. 59). The direction of growth was changed in this pseudopod after it came in contact with the outer segment of the desmid so that its advance was in towards the body-proper along the side of the desmid (*b* and *c*, Fig. 59). In the meantime the *Chilomonas* was inclosed at its second position (*2*, Fig. 59). Protoplasm overarched the somewhat triangular bay and eventually the specimen was crowded into a relatively small food vacuole and quieted"[1] by the *Pelomyxa*.

FIG. 60.—While pseudopods *a* and *b* of an *Amœba* were advancing along each side of a *Chilomonas*, they collided, at the same time, with a solid body. The growth of pseudopod *b* was now inhibited, while *a* advanced to contours *c* and *d* and finally surrounded the prey completely. ×200. (From Kepner and Whitlock.)

[1] Kepner and Edwards, l. c., pp. 390–391.

Again in *Amœba* "we saw an advancing pair of pseudopods, *a* and *b*, encounter a relatively large piece of foreign matter as they advanced about a *Chilomonas* which lay in position indicated in figure 60. At this synchronous contact of the two pseudopods the one *b*, was arrested while *a* advanced to contours *c* and *d*,

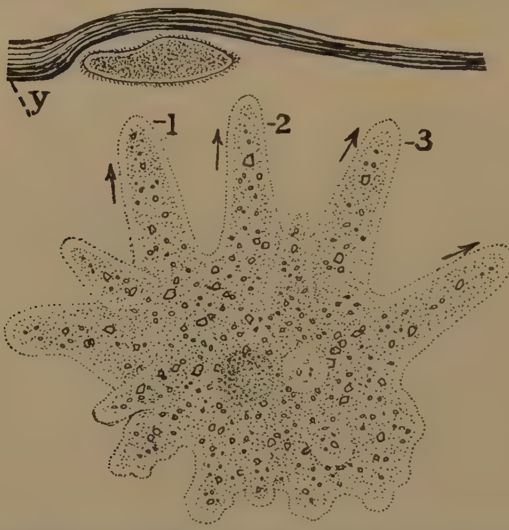

FIG. 61.—*y*, margin of a mass of detritus by which a *Paramecium* was lying. *Amœba* advancing toward the *Paramecium* along pseudopods *1*, *2*, and *3*. ×200. (From Kepner and Whitlock.)

d finally fusing with the body-proper. The *Chilomonas* was next overarched and captured." [1]

A very striking example of how an external object may become a factor in an *Amœba's* reaction to a motile object is seen in the case "of an *Amœba* ingesting a *Paramecium* that lay in a shallow bay by the side of a large brown mass of detritus (Fig. 61, *y*). The *Amœba* was advancing in a general way toward the *Parame-*

[1] Kepner and Whitlock, l. c., p. 402.

cium along pseudopods *1*, *2*, and *3*. As it approached the ciliate, pseudopods *1* and *2* widened and partly fused to form a large bi-lobed extremity, *m–m′* (Fig. 62). When this extremity had nearly touched the *Paramecium*, it sent out a small secondary pseudopod, *a*, beneath the prey, and *b* anterior to it. When the pseudopods *a* and *b* came in contact with the detritus, they

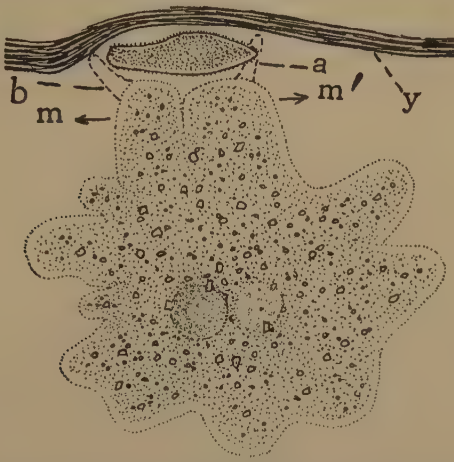

Fig. 62.—Pseudopods *1* and *2* of Figure 61 have widened and almost fused as *m* and *m′*. *m* and *m′* have sent out smaller pseudopods, *b* and *a* to the detritus. See next figure. ×200. (From Kepner and Whitlock.)

moved apart and became much stouter (Fig. 63). In the meantime a third pseudopod, *c*, appeared projecting from between *a* and *b* over the dorsal side of the *Paramecium*, while a pocket was formed within the body proper of the *Amœba* at the bases of these three pseudopods. The *Paramecium* first jumped to position *2*, Figure 63. The excited *Paramecium* next backed into the pocket of the body proper, *3*, and *a*, *b*, and *c* closed in and surrounded it completely." [1]

[1] Kepner and Whitlock, l. c., pp. 402–403.

Thus it is seen that an *Amœba* in meeting the contingency of escape of a prey shapes its reaction with reference to both the shape of its body and to external conditions, such as depth of water and presence of solid bodies.

After a reaction has been carried far enough to prevent the prey's escape, the reaction may be changed

FIG. 63.—Pseudopods *b* and *a* have grown stouter and moved apart. At the bases of *b* and *a*, a large concavity has formed. A third pseudopod, *e*, now formed and advanced over the *Paramecium* which moved from position *1* to position *2* and then to position *3*. It was then captured by the lips of the concavity converging. ×200. (From Kepner and Whitlock.)

to one such as is made when *Amœba* or *Pelomyxa* is reacting to a nonmotile organism. For example, "*Amœba* reacts to a free-swimming *Euglena viridis* by sending out pseudopods that widely embrace it. Sometimes, however, the embracing pseudopods close in upon the *Euglena* to hold it in a tight grip behind the position of the gullet, and this though the flagellum be quite active. On March 17, 1919, we saw a *Eu-*

glena caught in this manner at its anterior end. The projecting part of the flagellate's body was passive, but the flagellum was very actively lashing within the

Fig. 64.—A ciliate being captured by pseudopods *a*, *b*, *c*, *d*, while a *Euglena* has been grasped as it was retreating from a forming food vacuole. ×200. (From Kepner and Whitlock.)

inclosed bay. All movement for the time had ceased in the gripping pseudopods. This observation had lasted but a minute, more or less, when a large *Parame-cium*, coming up at right angles to the *Euglena*, col-

lided with it at the point indicated by the arrow in Figure 64, and dragged the *Euglena* free from the *Amœba's* grip. This was apparently the first step in the process of changing the second type of reaction into the first type. Mr. C. O. Dean, a student in this laboratory, observed an *Amœba* that had thus gripped a *Euglena viridis* and thereby cut off its chance of escape. After the *Amœba* had thus laid hold of the *Euglena*, its 'ectoplasm flowed out around the *Euglena*' on all sides and so close to the wall of the *Euglena* that there was no water present between 'the surfaces of the two organisms.'"[1] That such a change in reaction should take place is seen to be quite significant when we look into the details of this reaction. Schæffer and Edwards have shown that the wide embrace, similar to that *Amœba* makes of an object that is liable to escape, may be formed by an *Amœba* in reaction to an object that is kept trembling even though it is not food. It is quite probable, therefore, that when an *Amœba* approaches a *Euglena*, the lashing of the latter's flagellum sets up currents in the water which stimulate the *Amœba* in such manner that it sets to work to capture the *Euglena* in an indirect manner. In the example last cited, it is evident that the lashing of the flagellum of a *Euglena*, thus held, will stimulate the *Amœba* more now that it is held than it had done before it was captured, for after being thus captured the flagellum of the *Euglena* becomes very active. Since the beating and lashing of the flagellum becomes greater after the *Euglena* was held, the stimulation, as arising from this motile object, must have been greater to the *Amœba* and yet the reaction ceased

[1] Kepner and Whitlock, l. c., p. 403.

to be directed toward an object that had the power of escape. There was herein evidence that *Amœba's* reaction to food was qualitative as well as quantitative.

The qualitative nature of an *Amœba's* food-reactions is more apparent in "an *Amœba* reacting to a *Chilomonas* that had come to lie against the tip of a

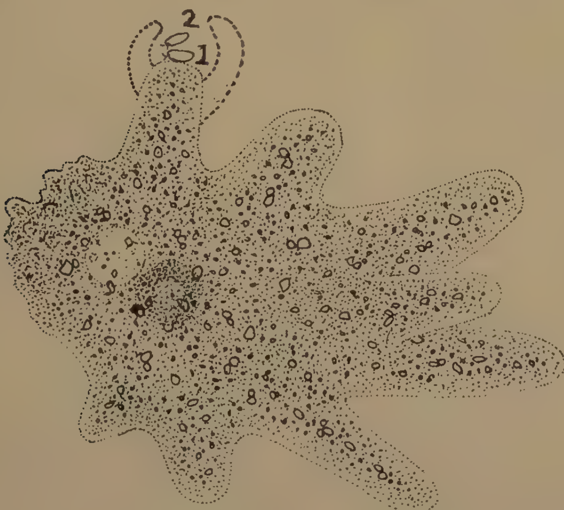

FIG. 65.—An *Amœba* capturing two *Chilomonases* which lie off the end of the parent pseudopod. ×200. (From Kepner and Whitlock.)

pseudopod (Fig. 65, *1*). The *Amœba* sent out two pseudopods in response to the stimulus. The smaller pseudopod arose from the side of the parent pseudopod and a little behind its end, while the larger secondary pseudopod came out quite a distance behind the tip of the parent one. The interesting feature of this reaction is the fact that the parts reacting to the source of stimulation are parts least stimulated; indeed, the

greater reaction was displayed by the least stimulated part. The quiet *Chilomonas* could stimulate the parent pseudopod in two ways: either chemically by means of its metabolic by-products, or physically by means of slight vortices that the play of its flagella may set up. In either case the ends and not the sides of the parent pseudopod would be most affected by these stimuli. Moreover, we have studied the types of vortices set up in the water by quiet *Chilomonases*. This study showed that in all cases the strength of the currents thus set up was greatest at the anterior end of the *Chilomonas*. Finally, as the two secondary pseudopods were coming out by the sides of the *Chilomonas*, a second *Chilomonas* came to lie at position *2*, Figure 65, and thus double, or at least increase, the sources of stimulation; but this did not modify the conduct of the two secondary pseudopods. These facts indicate that the *Amœba's* reaction is a qualitative and not a quantitative one."[1] *Chilomonas* had been lying with its flagella directed toward the left. When *Chilomonas* is not moving about, it usually sets up a vortex in the water which plays toward its anterior end. In both position *1* and position *2*, therefore, currents of water must be coming in toward the left side of the tip of the pseudopod of *Amœba*. The left side of the pseudopod must, therefore, have been more greatly stimulated by *Chilomonas*, whether the stimuli were either physical, chemical, or both. If the *Amœba* had reacted in a quantitative manner to this *Chilomonas*, the greater reaction should have arisen on either the tip or at the left side of the pseudopod. However, a reaction at the tip would have crowded the *Chilo-*

[1] Kepner and Whitlock, l. c., p. 406.

monas away. A less rapid reaction at the left would have given the *Chilomonas* greater chance to escape. With these facts in mind it becomes significant to see that the greatest reaction was not where the stimulation must have been greatest, but that it was greatest where the stimulation was least. Thus it appears that the food-reaction of *Amœba* and *Pelomyxa* is qualitative, not quantitative and is conditioned by the contingency of escape of its prey.

Therefore, just as man displays foresight in attempting to capture an animal that is liable to escape; so, too, an *Amœba* or a *Pelomyxa* displays a prescience, which is only approximated by the complex machines, behind which man's intelligence stands, and out of which intelligence these mechanisms have sprung. And if this appear to be not scientific, it may be that it is because organization presents something fundamental and that the simplest organism is more like man, because of its prescience, than is the most complex mechanism like the simplest organism.

Years ago, a distinguished anatomist said "I have dissected many human bodies and have never found a soul." To this the rejoinder may be made that I have studied many *Amœbas* and have always found something more than matter in each of them.

CHAPTER VIII

MATERIAL OF ANIMALS' BODIES

A child sees no relation between the parts of which its world is made. Children believe that boys and girls are not related; for boys are made of one set of objects while girls are made of a much nicer set of objects. No child sees a relation between the most animal-like plant and the most plant-like animal. The child thinks of his body as being made up of eyes, ears, mouth, head, hands, trunk, feet, and legs and does not realize that there may be a fundamental substance of which his body is made or of which both plants and animals are made. Aristotle, the great anatomist of the ancients, saw little more than a child sees in the structure of animals. In his *De Partibus Animalium*, he "distinguished the 'homogeneous parts' and the 'heterogeneous parts,' the former corresponding in general to what we classify as tissues (bone, fat, cartilage, flesh, blood, lymph, nerve, membrane, nails, hair, skin, vessels, tendon, etc.), and the latter being the larger members of the body (head, face, hands, feet, trunk, etc.). Theophrastus, the pupil and successor of Aristotle, taught in his *Historia Plantorum* that the plant body is composed of 'sap,' 'veins,' and 'flesh.'" [1]

In 1590 J. and Z. Jensen, of Holland, made a compound microscope. This was the first compound mi-

[1] Sharp, Lester W. (1921), "An Introduction to Cytology," New York.

croscope that had ever been made. The invention of this instrument and its improvement have made possible great progress in man's knowledge of the structure of both plants and animals.

In 1655, a botanist, Robert Hooke, prompted by a curiosity to know why cork would not sink in water, placed a thin slice of it under his primitive microscope. He was surprised to find that cork was not a homogeneous substance; but that it was composed of many hollow prismatic units. Each of these units he designated a cell. That was the beginning of a line of discoveries that has culminated in our now knowing that every animal- and plant-tissue has a common unit of structure—the cell.

But Hooke had not discovered the real cell. He found only the empty shells or walls that living cells had once built about themselves.

Later men came to see that there was a peculiar substance within these units of Hooke, when living plant and animal tissues or structures were examined. Robert Brown in 1831 discovered that this substance of the cells of the hairs of stamens of *Tradescantia* moved. In 1840 Purkinje suggested the name *protoplasm* for this substance that was found within living cells. During the decade from 1830 to 1840 two Germans, Schleiden and Schwann, were interesting themselves about the facts that pointed toward a common plan of structure for both plants and animals. In 1839 Schwann wrote "'The elementary parts of all tissues are formed of cells in an analogous, though very diversified manner, so that it may be asserted that there is one universal principle of development for the elementary parts of organisms, however different, and that this

principle is the formation of cells.' And further: 'The development of the proposition that there exists one general principle for the formation of all organic productions and that this principle is the formation of cells, as well as the conclusions which may be drawn from this proposition, may be comprised under the term Cell Theory. . . . . all organized bodies are composed of essentially similar parts, namely, of cells.'"[1] These words of Schwann stand out as a monument marking a great advance made by man in his acquisition of knowledge. Man had at last learned to think in a more generalized fashion concerning plants and animals. He had passed from particulars to a generalization. He had discovered that all plants and animals were made of one common substance—*protoplasm*, and that this substance was organized into cells. Huxley has defined protoplasm as the "physical basis of life." DuBois Reymond speaks of it as the "medium of vital manifestations." So in dealing with the material of animals' bodies we are led historically to this substance *protoplasm.*

It was not long after men realized the basic importance of this material that they sought to determine its chemical composition. Its chemical composition, however, "can be obtained only after life is gone, analytical processes invariably killing it. Nevertheless there is no loss of weight after death, so presumably the same chemical elements are present. Analyzed in bulk, material that has been living is known to contain Carbon, Hydrogen, Nitrogen, Oxygen, Sulphur, Phosphorus, Fluorine, Chlorine, Silica and metals Sodium, Potassium, Calcium, Magnesium, Iron, etc.

[1] Sharp, Lester W., l. c., p. 9.

The chemical composition is not easy to determine because protoplasm is not a homogeneous substance but a mixture of different substances; the elements given above are combined in a great variety of ways of which more or less definite compounds called albuminous compounds, or proteins, albuminoids, and nucleo-proteins (all of which are grouped together under the general term proteins) are universally present. Hoppe-Seyler in 1871, analyzing pus cells free from surrounding fluids, found the following percentages of substances:

Nuclein	34.257 per cent
Insoluble substances	20.566 per cent
Lecithin and fat	14.383 per cent
Cholesterin	7.40 per cent
Cerebrin	5.199 per cent
Undetermined albuminoids	13.762 per cent
Extractives	4.433 per cent

"In the ash he found sodium, potassium, iron, magnesium, calcium, phosphoric acid and chlorine. Since then a great variety of different substances have been obtained from cells and tissues of different living things, some of which are given in the following partial classification of the proteins.

Classification of the Proteins

A. Simple Proteins (albuminous bodies)	Albumins Globulins Glutelins Prolamines Albuminoids Histones Protamines	Uric acid Xanthine l-methylxanthine Heteroxanthine Theophylline Paraxanthine Theobromine

B. Conjugated Proteins	Nucleoproteins	Nucleic acids	
		Purine bases	Caffeine Hypoxanthine Guanine Epiguanine Adenine Episarkine Carnine
		Pyrimidine bases	
	Glycoproteins		
	Phosphoproteins		
	Hæmoglobins		
	Lecithoproteins		
C. Derived Proteins	Primary derivatives	Proteans Metaproteins Coagulated proteins	
	Secondary derivatives	Proteoses Peptones Peptides	

"The above list does not give anything like a complete enumeration of the chemical compounds which make up protoplasm. Most of the above are merely compounds of C, H, N, O, and P, and vary in the relative percentages of the different elements of combination. In the list only the derivatives of the purine bases are given, but each of the others includes a similar list of substances. Add to these many compounds the various combinations of carbohydrates and fats, and of the minerals Ca, Na, Fe, Mg, etc., and some faint conception may be gained of the enormous number of chemical bodies to be found in protoplasm.

"Chemically, living matter may be summarized as consisting of proteins, fats, carbohydrates and salts, the latter playing some important part in the vital processes although, since they do not appear in all types of protoplasm, each cannot be regarded as a *sine qua non* of living matter. The absolutely essential elements are carbon, hydrogen, nitrogen, oxygen, and phosphorus which enter into the composition

of pure nucleinic acid and form the basis of all protoplasm.

"While chemical analysis gives an idea of the kinds of elements entering into the composition of protoplasm after death, it allows no conception of the numbers of chemical bodies that are continually being formed during life, and still less conception of the nature of the vital chemical processes. It is generally agreed that pure, ash-free proteins are really inert and lifeless and that salts or electrolytes, either organic or inorganic, are necessary for the vital activities.

"Chemical composition, therefore, does not carry us very deeply into the mysteries of protoplasmic composition, nor does it give any clue to the nature of the vital processes. It shows, however, what chemical elements are essential for continued life, *i. e.*, what elements are necessary to provide for in the food, for all living things are constantly using up these substances in vital activities and replacing them from the food materials selected from the environment." [1]

The chemical nature of protcplasm reveals the fact that the bodies of men and beasts are composed of some of the elements of which the universe about us is formed. Nitrogen, phosphorus, carbon, hydrogen, oxygen, etc., such as men may find in a distant planet or star, likewise enter the composition of one's own body.

But naming these elements will not yet tell us of what our bodies are constituted.

We shall have to find out of what hydrogen is made and how it is constituted. Twenty-five years ago I was told that hydrogen could be resolved into atoms. These atoms were ultimate entities of matter; they were abso-

[1] Calkins, Gary N. (1914), "Biology," New York, pp. 7–9.

lute so that no smaller object could enter one of them—not even the ether of space; and they were immutable. No generalizations could be made then which would reduce the elements, that entered the structure of an animal's body, into one common substance.

But now I am told by the chemists of to-day that the elements are not immutable and that through a series of changes all of the present elements must have come from some primordial substance. I am further told that the atom is not absolutely solid. An atom of hydrogen, for example, is composed of two units: (1) a proton that occupies the center of the atom as its nucleus, and (2) an electron which lies by the side of the nucleus. The electron is supposed to rotate about the proton as the planets move about the sun. If we were to magnify the atom of hydrogen until its proton and electron would each be the size of a pea the radius of the electron's orbit, in which it moves about the proton, would be 25,000,000 miles. That would mean that if you were to draw a circle with a diameter of 50,000,000 miles and have within it only two objects each as large as a pea, you'd get a conception of how solid or nearly empty an atom of hydrogen was. So that in trying to find out of what protoplasm has been made, I have come to learn in the past twenty-five years that it at least is not made of solid bodies known as *atoms;* but that it is made of protons and electrons; and Sir Ernest Rutherford suggests that the day may come when we shall find that even protons and electrons may be little microcosmoses penetrated by the ether of space.

So far as our present knowledge of the ultimate constituents of protoplasm goes, then, we must be content to call them protons and electrons.

But again we must not forget that naming objects does not tell us what they are. What are protons and electrons? Are they mass or are they constituted of energy? The physicists do not seem able to tell us. One English physicist has said that on Mondays, Wednesdays, and Fridays he thinks in terms of mass, while on Tuesdays, Thursdays, and Saturdays he thinks in terms of energy.

Thus it has come about that biologists have shown us that animals' bodies are composed of protoplasm; the chemists have shown us that dead protoplasm is composed of elements; and the physicists have shown us that they do not know what the composition of the elements is—whether it be mass or energy or both. As I look back over my personal development, therefore, I find that twenty-five years ago I was told what matter was; to-day I am given additional facts and modify my conception of matter's composition; and based upon the experience of the past and the suggestions thrown out by the physicists, I hold myself ready to further modify my conception concerning the elements that make up the external things of the unknown world about me. Despite this change in my conception of what matter is my own self stands out in my own experience as the only real entity. The same person who learned what matter was, as men knew it twenty-five years ago, is now learning something further concerning what matter is. Thus it arises that my knowledge of self comes to be more real than does my knowledge of that that occupies space. Another contrast between that that knows and the transitoriness of that that occupies space is apparent in animals lower than myself. Generations of creatures equipped with in-

stinctive knowledge come and go in their physical entities and yet their instinctive knowledge persists.

This contrast becomes more conspicuous in the light of another fact concerning the material of which animals' bodies are made. This contrast is made evident by the fact that an animal's body is but a focal region through which matter is streaming.

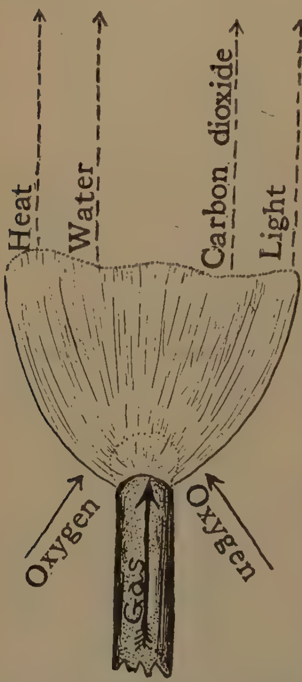

Fig. 66.—Gas flame as a focal region through which matter is streaming. The reduction of the amount of matter (gas) entering the flame will result in reducing its size.

A gas flame is also a focal region through which matter is flowing. And yet this flame retains a certain individuality and might have a contour as given in Figure 66. Into this flame matter in the form of illuminating gas and oxygen is streaming. From it matter is streaming in the form of water and carbon dioxide; while at the same time energy is being liberated as heat and light, for within the flame changes have taken place and new combinations have been made. If by any means the amount of matter entering this flame be cut down, the flame's size will be reduced accordingly.

So too with an animal's body. It, too, retains a certain individuality. And yet the body represents but a focal region through which matter is flowing. Matter

enters this focal region on one side in form of food, drink, and oxygen. Within the body, these various forms of matter enter new combinations. They leave the body as water, carbon dioxide and urea; while at the same time energy is liberated as heat and motion. If by any means the amount of matter entering the body be cut down, the body's size will be reduced. Figure 67 shows the difference in size between a *Paramecium* fed and one that has had food withheld from it. This also holds for each cell of a multicellular animal's body. The rate of flow of matter through a cell may be taken as a criterion of its rate of metabolism. In the cortical cells of the human cerebrum the metabolism is high; so through these cells matter is very rapidly streaming. So general is this overturn of matter in the human body that physiologists have estimated that once in each period of seven years the body has entirely replaced its original substance with new. If this be the case, that was a foolish little Japanese, who, after living in the United States for twenty or more years, decreed that when he died his body should

FIG. 67.—Right: a well-fed *Paramecium*. Left: a specimen from which food has been withheld. (From Calkins.)

be cremated and the ashes sent back to dear old Japan from whence they had come. His body in life had been a focal region through which matter had been streaming in such manner as to maintain the configuration of a Japanese; and as a result of this fact American and not Japanese ashes had been sent back to Japan. What had remained of Japan in him were his personal knowledge of Japan and his Japanese configuration.

In the fact that he had retained a record of the past despite the fact that the materials of his body were not transient, the analogy between a gas flame, as a focal region, and an animal body, as a focal region through which matter streams, breaks down.

A college freshman who had seen a gas flame to-day would realize the utter impossibility of expecting the gas flame to recognize him to-morrow; for when the morrow would come the material then in the flame would not be the material that had confronted him the previous day. If this same freshman, however, upon returning home at Christmas, were to find a certain maiden unable to recognize him as the man that had left her for college in September, he would not be satisfied to have the failure in recognition explained by having it pointed out that physically the maiden was not the same at Christmas as she had been in September. Though matter had been flowing through her cortical cells and other protoplasmic units for the months that had passed in his absence, he would expect more of this living "flame" than he would of the flame of a gas lamp.

The gas flame is a passive region through which matter flows in a fixed manner; whereas, the body of a maiden, man or animal is a region through which

matter passes under an organically *regulated control.* This regulated control arises out of the experience of the individual or that of its race or both. For example, one may not be able to predict the behavior of a strange dog which he would kick out of his path. "Science may some day enable us to predict the actions of the dog from the study of his body; but I do not see how we are to understand them without studying the conditions under which he and his ancestors have passed their lives. Whether he shut his eyes, throw back his ears, and, straightening his tail, plant his teeth in my leg, or crouch at my feet, with his muscles relaxed, his ears pendent, and his tail trailing on the ground, or, putting his tail between his legs, run away howling, the reason for his conduct is not the pain of the blow, but the importance of escape from the further injury which may follow. The means which he adopts are those which have been favorable to this result in the past history of dogs.

"The dog, no doubt, knows, just as we do, that, in the ordinary course of events, the attack is a sign of a disposition to do him further harm; and he also knows he may arrest or avert this by doing something, on his own part, to meet it; but, in case of most organisms, we know only the response and not the consciousness of it.

"The kick is a sign of something which may follow, and the actions which do follow are not the effect of the kick, for they are directed or adjusted, either consciously or unconsciously, to an event of which it is only the forerunner. This is what we mean, or at least an essential part of our meaning, when we say the dog is alive, while the stone is not. It is possible that the properties of the stone may be useful to the stone,

but these words are meaningless to us; although we do know that the properties of the dog are useful to the dog or to his species. The changes in the stone are the effect of the blow; while those in the dog are, in some way, the result of the past history of the dog and of his ancestors; for, all through this history, violent assaults have been associated with danger of further violence. This difference is as wide as the difference between life and its absence."[1]

The same difference is felt when we compare an inanimate bell with a bell-shaped unicellular animal. As I return several times a year to my paternal town, I hear the same school bell calling out with the same note that used to call my tardy feet to school and the same church bell ringing out the same note that brought my more tardy feet to Sunday School each week. These bells have been hit more or less regularly for thirty years. They to-day are responding to their respective clappers as they did three or four decades ago. So it is always with a dead bell. Hit it once and there is a "ding." Hit it again and again, there is a "ding." The bell will ever respond to the present blow without reference to the past blows. But it is not so with a unicellular living bell. Tap upon a vessel that contains an expanded *Vorticella* (Fig. 18, *A*) and the little bell-animalcule will contract (Fig. 18, *B*). Tap again after it has expanded and it will contract as it did the first time. So far it appears to be like an inanimate bell in that it is responding only to each present blow; but eventually a point will be reached when the *Vorticella* will no longer contract in response to the blow—and this is not due to fatigue. So we see

[1] Brooks, Wm. K. (1899), "The Foundations of Zoölogy," New York, pp. 52 and 53.

that when you tap upon a living bell it's "ding." Tap again and it's "ding" plus a little of the past, tap a third time and it's "ding" plus a little bit more of the past; and so in time you'll reach a point where there is so much of the past that there'll be no "ding." The reactions of the inanimate bell are the result of the present conditions; whereas those in the living bell (*Vorticella*) are the result of the present conditions plus so much of the cell's past history as will be demanded by the animal to make a regulated response.

This difference between dead objects and living objects persists despite the fact that men are learning more and more of the structure of cell complexes and how things in life are brought to pass.

Morgan and his students, for example, have, by a brilliant series of observations, made known that the loci of the hereditary factors or genes could be located on the chromosomes in an egg. These genes will determine such characters as yellow body, white eyes, miniature wings, long wings, vermilion eyes, etc. in the imago that arises from the egg. It is remarkably intimate knowledge of the material of a fly's body that has thus been attained. Twenty years ago no one would have dreamt that men would have known the germ-plasm of a fly so well as to have been able to make a "map" of a chromosome in which the position of each of a series of factors or genes would be given. Morgan and his students have come to know thus intimately the substance of the cell complex of which *Drosophila's* zygote is made.

Then again another line of biological knowledge had been opened when Pasteur undertook the control of disease through working with antitoxins.

The effect of the presence of an antitoxin is sometimes a matter of common observation. I know of a dog that was bitten by a rattlesnake and eventually recovered. After this recovery the dog was not seriously affected by the bite of rattlesnakes. Bee keepers sometimes become immune to the painful effects of a bee's sting. Folks entering a place where there are many mosquitoes find that the mosquito bites eventually cause them much less irritation than they had done at first. Just what all this means can be shown by experiments that have been carried out on Guinea pigs and other animals. If a small fraction of a lethal dose of cobra venom be injected into the veins of a Guinea pig, it will become ill for a time and recover. This may be kept up, increasing the dose of venom or toxin each time, until eventually the Guinea pig can stand the injection of many times a fatal dose of cobra poison. If now some of this pig's blood be drawn and the serum separated from it, the serum will be found to differ from the blood of an ordinary Guinea pig that had not been thus treated. For if a small amount of this serum be injected into a normal Guinea pig it also will be made immune to the bite of the cobra. Such immunity will not result if serum from the blood of an untreated pig be used. Thus it appears that in reacting to a poison that enters it, a pig's body builds a certain substance that reacts against the poison. The poison in this case was the substance that incited the response of the body. Such inciting substances are called *antigens*. The material elaborated by the body to counteract the *antigen* is called the *antibody*. When the antigen is a poison or a toxin the antibody is known as an *antitoxin*.

An interesting application of the presence of antibodies in the blood is now being put into practice. If, for example, a blood clot be suspected of being human blood, an animal, like a Guinea pig, will have some human blood injected into its veins. This will be done repeatedly until the Guinea pig's blood has elaborated antibodies against the foreign human blood. The blood will then be taken from the Guinea pig and allowed to stand until the serum has separated from the corpuscles and fibrin. This serum is a transparent, colorless fluid, looking much like water. A very small part of the clot of blood of unknown origin will now be soaked in a salt solution. When some of the salt solution, in which the unknown blood has been soaked, is added to the Guinea pig's serum, that had been exposed to human blood, a white precipitate will be formed in the serum if the blood clot had been human blood. No other blood than human blood will give this precipitate in the serum that had come from blood exposed to human blood, except the blood of the anthropoid apes. And in the case of the latter the precipitate will not be as dense as it is when human blood has been added to the saline solution.

Another subtle form of matter in the animal's body is met with in the form of substances that control the coördinated growth and functioning of tissues and organs. These substances are known as hormones.

Perhaps all the secondary sexual characters are determined by the presence of hormones thrown into the blood stream by the sex "glands" or gonads. The removal of the ovary from a chicken will not cause marked change in the hen's appearance. If, however, in place of her ovary, a testis from a cockerel be en-

grafted within her body, she will develop the large comb and conspicuous plumage of the male chicken. In this case, the foreign testis has secreted hormones into her body which specifically have stimulated the growth of such secondary sexual features as are characteristic of the cockerel. Because of her foreign hormones the hen has come to resemble a rooster.

Hormones appear in man at puberty and change the boy's vocal chords in such manner that the boy's voice is replaced by the deeper voice of man at the same time the action of hormones cause the beard to appear.

Hormones in man may even be responsible for the emotions that lie behind O'Henry's words "In May cupid shoots blind-folded—millionaires marry stenographers; wise professors woo white-aproned gum-chewers behind quick-lunch counters; schoolma'ams make big bad boys remain after school; lads with ladders steal lightly over lawns where Juliet waits in her trellised window with her telescope packed; young couples out for a walk come home married; old chaps put on white spats and promenade near the Normal School; even married men, grown unwontedly tender and sentimental, whack their spouses on the back and growl: 'How goes it, old girl?'"

The decline of a certain hormone's activity makes a father realize what will cure his son's troubles, as did James Whitcomb Riley when he wrote

> You smile and smoke your cigar, my boy,
>   You walk with a languid swing,
> You tinkle and tune your guitar, my boy,
>   And lift up your voice and sing;
> The midnight moon is a friend of yours,
>   And a serenade your joy—
> And it's an age like mine that cures
>   A trouble like yours, my boy.

But with all this advance regarding the intimate, detailed knowledge concerning germ-plasm of animals and new information concerning hormones the dividing line between dead and living things still persists.

"If in some ways the advance in physiology seems to have taken us nearer to a physico-chemical explanation of life, in other ways it seems to have taken us further away. On the one hand we have accumulating knowledge as to the physical and chemical sources and the ultimate destiny of the material and energy passing through the body: on the other hand an equally rapidly accumulating knowledge of an apparent teleological ordering of this material and energy; and are at a loss for a physico-chemical explanation." [1]

We seem to be following a dualistic series of phenomena to-day just as in the past. Bateson to-day writes as did Huxley. The former says: "The properties of living things are in some way attached to a material basis, perhaps in some special degree to nuclear chromatin; and yet it is inconceivable that particles of chromatin or of any other substance, however complex, can possess those powers which must be assigned to our factors or genes. The supposition that the particles of chromatin, indistinguishable from each other and indeed almost homogeneous under any known test, can by their material nature confer all the properties of life surpasses the range of even the most convinced materialism." [2] Huxley wrote: "Modern science admits that there are two worlds to be considered, the one physical and the other psychical, and that though there is a most intimate relation and inter-

[1] Haldane, J. S. Quoted by McDougall in "Body and Mind," p. 236.

[2] Bateson, William (1916) "Review of Morgan's work," Science, N. S., Vol. XLIV, p. 542.

communication between the two, the bridge from one to the other has yet to be found; that their phenomena run, not in one series, but along parallel lines." [1]

So far as science can carry him, the man of the world is confronted with two facts—(1) the material of which his body and the universe are made and (2) his own conscious, knowing personality. Concerning the former, science has not told him what it is and secondly science has shown him that his body is but a focal region through which this unknown material is streaming. Whereas, a definitely known fact persists in his life and that is that he is he. It is he that works with this unknown world and the objects therein. He appreciates that he is unique, for he may scoff, as did a Frenchman at the sun, "Sun I am greater than thou. Thou might fall upon me and crush me. But thou wouldst not know thy victory whereas I would know my defeat."

Many scientists do not realize the importance of this distinction between a personal being and the sun. Personality with them is but by-product, an epiphenomenon. The attitude of such scientists will some day be the subject of historical record, as C. H. Judd says "Some day the historian of thought will write it down as one of the curious fallacies of immature science that certain physiologists, biologists and even psychologists were satisfied to call their own personalities mere by-products without significance in the world, just because they did not find consciousness capable of description in the regular scientific formulas adapted for the discussion and explanation of external reality. One hardly knows how to find phrases in which to answer those

[1] Huxley, Thos., "Pseudoscientific Realism," p. 62.

who hold consciousness to be less real and potent than physical forces." [1]

To me it seems, therefore, that the man who believes in the reality of his spirit is less a man of faith than he who believes in the reality of his body and the things of this world.

[1] C. H. Judd, "Psychology," p. 62.

CHAPTER IX

CHOICE

In the inanimate realm all response to forces is passive. Water, in a passive manner, flows in response to the play of gravity; small particles, in Brownian movement, dance, in a passive manner, in response to the conditions that play upon them. So everywhere among inanimate objects—be they macroscopic or microscopic—there is but passive response to conditioning factors.

That animals accept and reject alternatives, in meeting contingencies, indicates that they are not passive. Animals, in reacting to conditions that may play upon them, are capable of effort. Jennings, in following the movements of an *Amœba proteus* after an encysted *Euglena*, said "The whole scene made really an extraordinary impression upon the observer. . . . One seems to see that the *Amœba* is trying to obtain this cyst for food, that it puts forth *efforts* to accomplish this in various ways, and that it shows remarkable *pertinacity* in continuing its *attempts* to ingest the food when it meets with difficulty."[1] No observer following the movement of a drifting leaf or of a rolling stone would be tempted to read into it "efforts," or "pertinacity." The trees in a forest are not passive objects, each tree is in its way seeking optimum conditions of life. Even the twigs of a given

[1] Jennings, H. S. (1904), "The Behavior of Lower Organisms," Washington, D. C., p. 197.

tree seem to vie with each other for position with reference to the source of their basic needs. The lowliest organisms have certain fundamental demands made upon them, that must be realized if the organisms are to live.

The existence of a stone, however, does not depend upon any such effort. A stone is not active. It is but passive. The stone gives and takes energy in a strictly passive manner. If the sun shines upon it, its temperature will rise; but later when the sun is not shining upon it, it will radiate some of its heat until it will have the same temperature as the other inert objects about it.

What holds good for the stone is also holding for all inanimate objects. The sun is radiating its energy to the planets and all other objects in space. These objects, in so far as they happen to have higher or lower temperatures than the other bodies in space, are either radiating or absorbing heat from one another. Thus among the inanimate objects there is a tendency which is carrying them to a point where all have the same temperature. When the universe has reached this condition wherein all of its objects have the same temperature, then the universe will have run down. Like a clock that has run down there will be no available energy in the universe and things will no longer move in it.

Against this tendency of the universe to passively run down, the effort of living things is directed. This is seen in the effort plants display in locking up energy photosynthetically or in the effort of man in harnessing wind, water-fall or tide. Inanimate objects make neither starch nor storage batteries. Energy with dead

objects is but incidental. Plants and animals, on the other hand, make energy a means to an end.

With living things energy is necessary for their very existence. "To be or not to be, that is the question" for even an *Amœba.* All living things must struggle for their very lives' sake. "It has long been clear to those whose eyes were not obstinately closed to the facts, that natural selection implies the struggle for existence, and that . . . this struggle is essentially teleological; sticks and stones . . . do not struggle for existence, nor, so far as we can see, do atoms, molecules, etherial vortex rings, or whatever may be the ultimate element of matter fashionable just now. All inorganic things seem content to remain in whatever condition it has pleased God to assign them." [1]

That there should be effort behind the evolutionary flux of life does not appeal to men who would be strictly scientific and nothing more. Such men have no place, in their conception of the universe, for *effort*, purpose, end, etc. For example: "Blood does not coagulate in order to prevent hemorrhage, but because certain chemical agents are present and certain properties. The fact that it does stop hemorrhage is quite incidental. It may have selective value, so that a species whose blood did not clot would have the worst of it in the struggle for existence, but it will never do to say that this chemical-physiological function originated for the purpose of preventing hemorrhage; for that would imply a mind at work in anticipation of the result." [2] This scientific attitude is again exemplified in the following: "We were intellectually intoxicated with the idea that

[1] "Body and Mind," p. 248, Wm. McDougall, 1915.
[2] John R. Murlin in "Science," Vol. LIV.

the world could make itself without design, purpose, skill, or intelligence: in short without life. . . . Such phrases set us free to revel in demonstrating to the Vitalists and Bible worshippers that if we once admit the existence of any kind of force, however unintelligent, and stretch out the past to unlimited time for such force to operate accidentally in, that force may conceivably, by the action of Circumstantial Selection, produce a world in which every function has an organ perfectly adapted to perform it, and therefore presents every appearance of having been designed, like Paley's watch, by a conscious and intelligent artificer for the purpose. We took a perverse pleasure in arguing, without the least suspicion that we were reducing ourselves to absurdity, that all the books in the British Museum library might have been written word for word as they stand on the shelves if no human being had ever been conscious." [1]

A final example of the scientific attitude toward life is shown in the following quotation: "If the fundamental proposition of evolution is true, that the entire world, living and not living, is the result of mutual interaction, according to definite laws, of the forces possessed by the molecules of which the primitive nebulosity of the universe was composed, it is no less certain that the existing world lay potentially, in the cosmic vapor, and that a sufficient intellect from a knowledge of the properties of the molecules of that vapor could have predicted, say, the state of the Fauna of Great Britain in 1869, with as much certainty as one can say what will happen to the vapor of the breath in a cold winter's day." [2]

[1] Bernard Shaw, "Back to Methuselah."
[2] Henri Bergson, "Creative Evolution."

The scientific attitude during the latter part of the last century left no place for choice or self determination to the individual living things about us or to ourselves for that matter. At this time "the rapid progress of physical and chemical science gave rise to a new wave of materialism; . . . physiologists, with few exceptions, began to regard Vitalism as finally overcome and to look confidently forward to the explanation of all the processes of living organisms in terms of physics and chemistry; growth was to be explained as a mere assimilation of molecules after the manner of the growth of crystals; secretion as a mere filtration or osmosis or as a conjunction of these two processes; all regulation of movement and of other processes by the nervous system as mere reflex.

"But now, after another half century of active physiological research, to which many hundreds of able men have devoted their lives, the achievement of the program so confidently laid down seems to have been brought no nearer. It has rather to be admitted that greater knowledge has revealed new difficulties on every hand; that no part of the program has been achieved; that no single organic function has been found to be wholly explicable on physical and chemical principles; that in every case there is manifested some power of selection, of regulation, of restitution, or of synthesis, which continues completely to elude all attempts at mechanical explanation." [1]

Mast, for example, in presenting a very logical explanation of the locomotion of *Amœba proteus* cautions his readers that this explanation will not account for the regulatory character of amœboid movement. In

[1] William McDougall, 1915, "Body and Mind."

the last chapter facts were presented which showed further that the *Amœba's* movement was qualitative and not quantitative and that it was directed toward meeting a contingency when such was present.

Restitution, too, stands in the way of realizing the program of the mechanists of the past century.

Dr. B. D. Reynolds and I observed some interesting

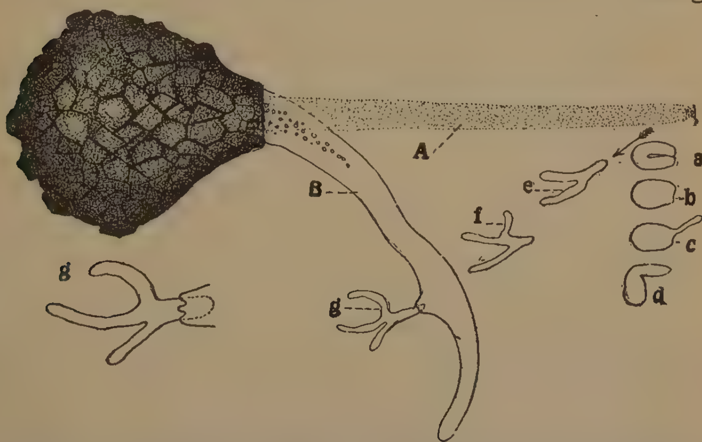

FIG. 68.—Pseudopod (arm) of *Difflugia*, *A*, withdrew suddenly and broke off fragment *a*. *a* changed shape as at *b*, *c*, and *d*. *a* then moved as *e*, *f*, and *g* to where a new pseudopod, *B*, met it and the two fused. (From Kepner and Reynolds.)

examples of restitution in *Difflugia*. *Difflugia* is a shelled rhizopod that sometimes so suddenly retreats into its shell that the end of its retreating protoplasm is whipped off. If no further disturbance is met with, the lost fragment will travel toward the body from which it has been broken, while the parent cell will, in turn, travel toward it. In time the fragment and parent cell will meet and the two will quickly coalesce with the result that the animal has been made whole again (Fig. 68).[1] In this manner the *Difflugia* adjusts

[1] Wm. A. Kepner and B. D. Reynolds, 1923, Biologial Bulletin, Vol. 44.

itself to the risk of permanently losing protoplasm when it hastily retreats from some threatening condition.

Regulatory effort and restitution should appeal to the average mind as sufficient evidence to show that "the materialistic position that there is nothing in the world but matter, force, and necessity, is as utterly devoid of justification as the most baseless theological dogmas." [1]

Huxley held "that our volition counts for something as a condition of the course of events." [2]

Macallum ('23) says "the mucosa is, in its properties and functions, something very much more than a physical membrane. Because its superficial layer is composed of living cells it is not, it cannot be, a passive element, for the cells have, as living units always have, the capacity to accept or reject whatever constituents of the chyle there may be." [3]

An English author, Sir T. Clifford Allbutt ('20) in referring to the constancy of bacterial species says: "If things be so, surely we are face to face with a marvelous and far-reaching faculty, *the faculty of choice*, and this rising from the utter bottom of biology to the summit—formative faculty—'auto-determination,' or if you please, 'mind.' Can the microbe do as the retriever does when with a hare in his mouth he comes to a gate; he tries this way and that, then thrusts the hare under the gate, leaps over and pulls the hare through? So the microbe tries it on, this way or that, till it succeeds, by self-education in the school of experience—*Bildungstrieb.* This is far more—radically more—than '*élan*

[1] Thomas Huxley, "Lay Sermons and Addresses."

[2] L. c., pp. 144–145.

[3] A. B. Macallum, "On the Urgency of Research on the Great Portal to Disease in the Body," Science, Vol. 57, p. 192.

vital,' not merely energy but *choice*—plasticity driven to choose or fail." [1]

Thus the physiologists of the present day in contrast to those of the past half century are recognizing freedom in the mucosa cells of the human intestine; in connection with the vital phenomena of bacteria and speaking of choice as extending from "the bottom of biology to the summit." "The circumscribed nature of ordinary chemical action and the freedom of human volition, notwithstanding its elemental background, are two different things."

There may be a place, therefore, for the word *choice* in a vocabulary that deals with animal activities.

When I use the word choice in this chapter I do not mean to imply that there is a trace of self-consciousness implied. A man walking in his sleep may instinctively select the proper alternative in order to take a step safely across a dangerous place and yet in selecting the safe, as over against the dangerous alternative, he would in no way have to be conscious of having made the choice. Choice is used as the psychologist uses it when he says "If quickness of choice can be taken as a measure of the ease of discrimination, it is probable that the crows are capable of distinguishing much smaller differences" [2] than that between a circle of 5 centimeters and one of 4.5 centimeters.

In what has been said in previous chapters it was implied, if not stated, that even an *Amœba* was free to accept or reject certain alternatives. All animals are capable of a range of freedom in determining which of two or more alternatives to accept. In so far as this

[1] Sir T. Clifford Allbutt, "Medical Research," Science, Vol. 52, pp. 117–118.
[2] Chas. A. Coburn (1914), "Journal of Behavior," Vol. 4.

range of freedom becomes wider we pass from reflex conduct, through instinctive conduct, to intelligent activity.

Tissues and animals, that live under a greatly restricted or constant environment, display little more than reflexes. There are some animals that live under conditions that are as constant as are the conditions under which tissues are involved in the "knee reflex" of man. These animals show little range of variability of action. Such animals must closely approach the inanimate in their reactions to stimuli. Mechanists point to them as being creatures without choice and doing what they do only because of the material configuration which the past has given their bodies. But even here the reflex conduct meets the demands of the daily life of the animals and their reflexes are directed toward some end. A certain amount of choice is displayed on the part of such animals.

When we examine the reflex conduct of an incomplete organism or organ the suggestion of choice in the conduct becomes *nil*. There is an end apparent in the normal reflex conduct of the proboscis of a *Planaria*. Dr. Arnold Rich and I observed that, by destroying certain neural centers of *Planaria albissima*, its proboscis would undergo auto-amputation. The proboscis thus freed would swim about as an independent organism ingesting or swallowing every small object that it would encounter. But in this reflex conduct it displayed no choice. Swallow, it had to; so that if we placed small particles of glass in its path, these would be taken in. The proboscis would even turn upon the body of which it had formed an organized part and eat its way through from one side to the other (Fig. 69). When this organ

is under the normal inhibitory control of the animal, as a whole, it displays a very evident faculty of choice

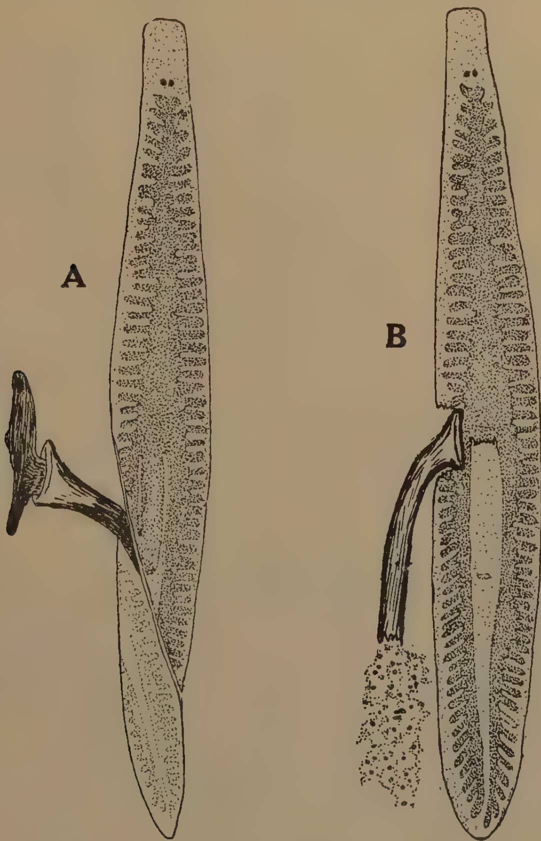

Fig. 69.—*Planaria albissima.* *A*, normal specimen feeding. *B*, the proboscis severed from the body feeding upon the body-proper of which it had formed an integrated part.

in that it nicely chooses between food and nonfood. In normal life, therefore, we have the proboscis of *Planaria* displaying choice, whereas it is only when it is de-

tached from its body proper that it shows a purely mechanical reflex in which no choice is apparent.

In instinctive conduct the range of choice becomes wider. For example, an ichneumon fly (Fig. 70), does not drill a hole into any piece of wood; but selects a particular tree and a definite region of this tree. She seeks further a region in a tree within which by boring with her ovipositor she may penetrate an excavation of

Fig. 70.—An ichneumon fly drilling into wood for ovipositing. (From Kellogg.)

the larva of a fly, hornet fly, and deposit an egg therein. So in all instinctive conduct choice is apparent.

It is not necessary to indicate to the lay reader that human beings acting intelligently can choose between two alternatives.

Just as the various orders of conduct differ in the range of alternatives that confront them, so the animals differ. The simplest accept or reject alternatives from a strictly utilitarian basis. In this respect, an *Amœba* can recognize the difference between food and nonfood. An *Amœba* is similar to a cow. Some one has said that

if you take a cow up onto a mountain top she will see two things: cow-food and not cow-food. So with all the low animals, they are not carried far beyond the realm in which they see but two things: food and nonfood.

Perhaps some of the higher animals can accept or reject objects from the standpoint of the beautiful and the homely. The bower bird is apparently able to select colored objects with which to decorate its abode. J. R. Slonaker has found that birds have in their retinas a preponderance of color-seeing cones, while in the retinas of mammals there is a preponderance of ray-seeing rods.[1] The peacock and other small birds display their plumage as though they were aware of the quality and appearance of their handsome feathers. Certain apes may be able to select the symmetrical and the handsome objects as over against the asymmetrical and homely ones. But when all has been said by way of giving full credit to these higher animals, one cannot grant them a wider range of choice than that of accepting food as opposed to nonfood and certain primitive qualities of the beautiful as opposed to the homely.

Certain it is that these lower animals are not confronted with the dilemma of Shakespeare's clown in which he finds himself confronted by the alternatives: "Fiend says budge! Conscience says budge not!" Or again "Dogs do not lie awake at night brooding over the sins they had committed during the day."

The alternatives of the clown arise out of the fact that man has evolved to where he has need for the personal pronoun. Men may some day discover that the ape has a language. But in that language's vocabulary men

[1] Journal of Morphology, Vol. 13.

will not find the equivalent of the words "I" and "you"; for the apes have not become clearly self-conscious.

Man, having evolved to where he has need for the personal pronoun, is at once confronted with the alternatives: right and wrong. These alternatives confront all men. Woodrow Wilson in an address before the American Bar Association on October 20, 1914, said "I have in my life dealt with all sorts and conditions of men, and I have found that the flame of moral judgment burned just as bright in the man of humble life and limited experience as in the scholar and man of affairs."

Men are confronted by necessity of making moral judgments; apes and birds may be confronted by the necessity of making utilitarian judgments between food and nonfood and perhaps have the power to discriminate between the beautiful and the homely. In the lowest animals one cannot recognize a power of discrimination higher than a utilitarian one, involving food and nonfood. Thus it appears that animals vary in the degree to which they possess a power of discrimination or choice.

An animal, that does not exercise to the full its power of discrimination, imposes a handicap upon itself. If, for example, an *Amœba* ceases to exercise the power to discriminate between food and nonfood, it may take into its body much material that would be worthless or even injurious. In either case a handicap would be imposed upon it. A bower bird refusing to discriminate between the materials ordinarily used in decorating its bower and other objects might be handicapped in its efforts to maintain itself and its species. So throughout the animal kingdom, failure to exercise to the full the individual's power of discrimination

results in retrogression. A man early suffers decline if he ceases to discriminate between food and nonfood. He will also suffer retrogression if he fail to develop his æsthetic tendencies. But man's power of discrimination does not end with the utilitarian question of food and with æsthetic development. He is a unique animal in that, having the personal pronoun, he must discriminate between good and evil. If he fail to discriminate between these alternatives, he suffers decline.

Bergson maintains that "consciousness seems proportionate to the living being's power of choice."[1] This reminds me of the old statement that "In plants life is soundly asleep; in the brutes it is dreaming, while in man it is awakening."

Man's consciousness during historic times has been awakening. History records the days when men discriminated between right and wrong on the basis of might. To the peoples of ancient Nineveh, Babylonia, Syria, and Egypt might was right. Out of the bloody effort of this struggle of early humanity came the Jewish ideal that justice was right. In the days of ancient Israel men sought to discriminate between justice and injustice. Men now are seeking to deal not merely justly but charitably with their fellow men. In so far as men succeed in discriminating between the charitable and the uncharitable they are exercising their full power of discrimination and are evolving.

It behooves modern man, therefore, if he is to attain full personal development, to make a threefold choice. He must discriminate between food and nonfood; the æsthetic and the nonæsthetic, and the charitable and the uncharitable.

[1] H. Bergson, "Creative Evolution," p. 179.

CHAPTER X

SUMMARY

I have given examples of a wide range of animals that look into the future. This ability to look into the future is not encountered in the realm of mechanics, except in machines, behind which stands the mind of man (*e. g.*, the linotype). If animals show this prescience, plants should also do so; for they too are living things.

Ganong reminds us of the fact that a sailor, in following a path indicated by the compass is not interested in his immediate or present response to the compass's path as such. He then tells us that "The wide use of gravitation as a stimulus raises at once the question as to the physiological value of gravitation to the plant. In itself, however, it has no value, so far as any one has been able to discover. The plant has no object at all in sending roots downward and shoots upward merely to have them down and up; but it happens that down is the direction of moisture and minerals, which roots need, and up is the direction of light, which shoots need. No doubt those parts could be guided in the needful directions by their hydrotropism and phototropism respectively, but gravitation has this advantage over moisture and light as a stimulus, that, while happening to act in the suitable direction, it is present unvaryingly at all times, whereas light and moisture are most variable in quantity, and sometimes absent altogether. This is especially true of light, which is

missing at night when growth is most active and the guiding stimulus most needed. Gravitation, therefore, is neither a direct, nor a foster stimulus, like those we have already considered, but a substitute stimulus, adopted by the plant in place of other stimuli because it acts better than they. The use of the compass has just the same advantage over observation of the sun and the stars, which would also take the sailor to his port." [1]

In the use of this substitute stimulus plants may be considered to be showing a certain degree of prescience concerning their individual welfare.

Certain plants, like *Utricularia*, "Venus fly trap," and "pitcher plant," build up a complex of structures whereby insects and other small animals are trapped. These small animals are digested and absorbed by their captors. Herein, we have the plants clearly providing for certain contingencies. The individual plants are in all these instances benefited by the provision that they make for their future.

Many very interesting examples of plants providing for the maintenance of their respective species can be given. The mountain laurel has its stamens held in such manner that insect visitors will be dusted with pollen. When such dusted visitors go to the next flower cross-pollination is effected. The blue flag, or iris, builds a bumble-bee trap with a landing stage so constructed that the bumble-bee will spring a trigger, as it were, whereby the pollen grains from the bee's back will be deposited where cross-pollination will be insured. Many cases might be cited in which definite structures have been elaborated in order to insure prop-

[1] Ganong, Wm. F., 1913, "The Living Plant," p. 247.

agation, but I shall give but one other example, *Aristolochia clematitis*. In Figure 71, *A*, at *n* we have a downwardly-turned flap or process upon which pollen from another flower must be carried if seeds are to be formed in the pod (*hf*). The pollen-forming organs (anthers), *a*, are yet closed in this flower, while the mouth of the flower-tube is distended and erect. Within the narrow, tubular throat of the flower are many recurrent hairs, *r*. Small flies may push their way through these downwardly-turned hairs as they follow the scent of the nectar, that is at the base of the flower tube. So long as these hairs remain the flies that enter cannot leave the flower. Figure 71, *A* "shows a young flower in longitudinal section; the stigmatic surface *n* is just ready for fertilization, but the others are still closed. A small fly *i*, which has brought on its back a heap of pollen from an older flower, has just penetrated through

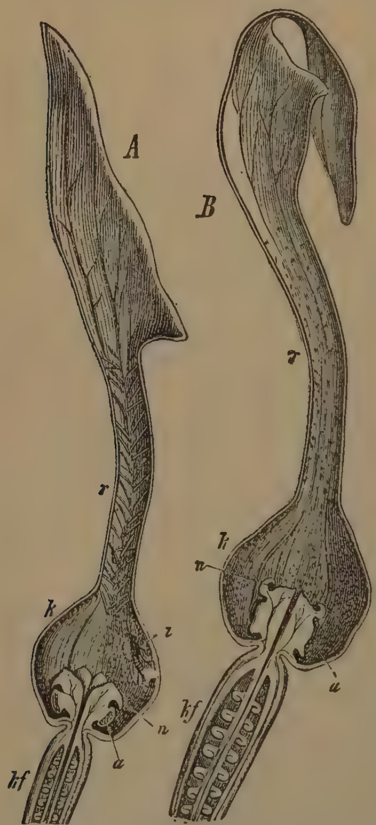

FIG. 71.—"*Aristolochia clematitis*. Flowers in longitudinal section; *A* before, and *B* after fertilization (enlarged—see text)." (From Sachs.)

the narrow throat of the flower, and is roaming about in the flask-like enlargement *k*. Not uncommonly six to ten such flies may be found in a flower: they are imprisoned and cannot escape, because the throat *r* of the flower is beset like a trap with long motile hairs, which offer no hindrance to the entrance of flies, but bar the passage out as in a weir-basket. While the insect is thus wandering around the cavity, it brings its pollen-laden back in contact with the stigmatic surface, and pollinates it, in consequence of which the stigmatic lobes curve upward, as in Fig. 451, *B*, *n*. As soon as this has taken place, the anthers, which have been closed hitherto, dehisce, and become freely accessible, at the same time, by the change in the stigma, and by the collapse of the hairs at the base of the enlargement, which now widens; the flies, having deposited on the stigmatic surface the pollen which they brought with them, can now therefore creep under to the open anthers where the pollen of the latter becomes attached to them. About this time, moreover, the throat *r* of the flower has also become passable from within; the trap-like hairs in it having perished and dried up as a result of the pollination of the stigma. The insect laden with the pollen of this flower, can now escape, and in spite of its late experience, it again forces its way into a younger flower, there to give up to the still receptive stigma the pollen it has brought with it. While the above changes are going on in the interior of the flower, the latter, moreover, alters its position. So long as the stigma in the young flower is still receptive, the pedicel is erect, and the perianth opens outward . . . presenting to the flies a hospitably open door; but as soon as they have ac-

complished the pollination of the stigma, the pedicel bends sharply downward at the base of the ovary, and when the flies, again laden with pollen, have flown away from the flower, the banner-like lobe of the corolla . . . closes over the mouth of the throat, stopping the entrance to the flies, which have now nothing more to do here." [1]

Everywhere, then, life seems to show a remarkable ability of providing for the future. One cannot say that he can see a bacterium meeting a contingency as does the *Amœba*. But that there is something peculiar to the locomotion of living bacteria, as over against the movement of inert material, as seen, for example, in particles displaying Brownian movement, is evident. For no trained person, when shown particles of inert material under Brownian movement, ever mistakes them for living particles; while no trained person, when shown moving bacteria, ever mistakes them for dead objects. There is a peculiarity of the locomotion of these extremely small plants that characterizes it as vital movement. Finally, even bacteria, too, make provision for the maintenance of their kind, whereby their respective species are carried successfully through periods of extreme vicissitude. Conditions that are lethal to the free bacteria are met by them by elaborating spores. Thus even bacteria provide for the welfare of their species.

Behind all life there is this effort to project the reaction into the future. Plants and animals struggle to provide for the mere physical welfare of themselves and their species. Man, however, seeks to attain not only mere physical necessities, like food, drink, and pro-

[1] "Physiology of Plants," Julius von Sachs. Translated by H. M. Ward, p. 793.

tection from the inclement forces of nature; but he also aspires to attain a realization of æsthetic and moral ideals.

Thus it happens that not only do the mere physical demands of life play upon and guide man's development but man's development involves in a peculiar sense the psychical and the ideals of the æsthetic and the moral.

In the progress of the lower animals it is the physical self that is obviously shaped to meet the demands of the future. For example, when the bat's progenitors instinctively began to fly, their hands and arms were more and more changed in form, to the end that they, in time, came to be wings.

In the progress of rational man, however, the physical self is less obviously modified to meet the demands of the future. When first men sought to fly they did not modify any part of their own bodies in the manner that the bat's progenitors had done; but they widened their knowledge of the physical things about them and so shaped and directed these external physical objects and forces as to create an aëroplane or an airship. Man's progress, therefore, is more obviously psychic than physical.

This psychic progress is driven by ideals rather than by physical necessity. Bread, it is true, is demanded by man. But "man does not live by bread alone."

This peculiarity of human progress is too little emphasized these days, when the success of the individual is generally recognized by the amount of physical wealth he can acquire.

Teachers have not taught as they should have taught. During the critical days of the World War

I met one of my old students. He was so well groomed and so prosperous in his bearing that I expressed an interest to know how he could be so prosperous selling certain commodities when the price of these same commodities was prohibitive to one of my friends. In reply to my expressed curiosity, he remarked: "It matters not about your friend. Let me tell you what the President of my firm did in September, 1914. He called together his Board of Directors and said 'Gentlemen, I wish you to give me all your available cash and all your collaterals. For I plan to borrow and buy until we can no longer borrow. This war presents an opportunity for us to make a pile of money.'" My old pupil boasted, with an educated man's boast, "And they got together $3,000,000 and now I am selling it for 100% profit." I listened to this boast. I recalled that the President to whom he had referred was a college man, too, and that this same President was, as a formal Christian, a pillar in a certain large Protestant church. I left my friend, realizing that some preachers had not preached well and that some teachers had not taught well, so long as a church member should thus be satisfied with the mere acquisition of wealth and so long as a formally educated man should thus boast of this acquisition.

Had parents, preachers, and teachers taught properly, this same President's reaction to the opportunity afforded by the opening of the war would have been different. I called the attention of this alternative to an aged friend in this manner: I told my friend that had this President been following the proper ideals of his civilization he would have called his Board together. This done he would have reminded them that their

corporation stood for service and that the time presented a peculiar opportunity to serve. "Therefore, gentlemen, let us borrow and buy until we can borrow no longer and then in a peculiar way serve our patrons by selling at the lowest price possible to maintain ourselves and our corporation." I told my aged friend had this been done, some day there would have been a monument raised to the honor of this President and his Board, the significance of which would have vied with that of the Christ of the Andes. My friend shrugged his shoulder and replied "You're correct; but that's not human nature." He might have been reminded that monkeys never became men by following monkey nature and men will never become more than men by following human nature.

Parents, too, are not teaching as they should. How often do we find mothers boasting of the amount of money their sons or the "successful" sons of their neighbors are making. So long as mothers' boasts are thus primarily based upon the acquisitive capacity of their sons, just so long the world may expect to hear of mothers' sons dying in the filth and awful distraction and desolation of the battlefields' trenches.

Human individuals cannot afford to ignore the moral factor in their environment. The prescient effort of men should be directed toward the attainment of moral ideals. In this attainment, alone, lies the ultimate strength, force and worth of the individual.

Nations, too, cannot afford to ignore this characteristic of human effort. "One thing seems to stand out most clearly, namely, that the moral sense of mankind, if outraged, is a mighty factor in determining success in the struggle between nations. Germany's failure

to realize this fact has cost her dearly. She has failed to conform to this salient failure of her environment and must reap the result of her unfitness for life as it is in some of its most fundamental aspects. The awful demonstration of the inviolability of moral truth, as of all other truth, may prove in the end to be worth far more than even its fearful cost." [1]

Even religion, divorced from the faculty to choose between right and wrong, is but superstition. Without the moral effort on the part of man there is left too little of that that is characteristic of life to lead to his higher development. The "process of realization" would be not sufficient in him. "Scientific observation or intuition (in this sense) discloses as a reality the constant or law-abiding and hence calculable element in phenomena; but superposed on this, and equally real and fundamental, is the creative element which gives nature its character as a temporal or historical process whose possibilities are never realized at one time, but always in a process of realization." [2]

The process of realization in man, who is clearly self-conscious, is primarily a matter of developing that that is most real in him and which persists as a growing entity, that I may call his *ego* or his personality. The matter that constitutes my body is no longer that that gave me a similar material configuration twenty years ago. And yet my durational or historical self has persisted and I am making use of the experiences that have come to me by way of further extending and realizing this historical or durational self, or personality. In this effort our most satisfactory teacher,

[1] Metcalf, M. M. (1918), "Darwinism and Nations," Anat. Record, May, 1918.
[2] Lillie, R. S. (1920), "The Place of Life in Nature," Journ. of Phil., Psyc. and Scientific Methods, Vol. 17, p. 493.

Christ, has come to guide us, not that we might inherit the things of this world or that a state, nation or even church might be built up, but that we may the better attain our personal realization. In short he came not that we may have life, but that we may have it more abundantly.

His teachings center about the "outstanding fact of the Universe," to use Dr. Haldane's phrase. This is not the sun, the source of all energy; not the earth, the source of man's sustenance; nor even the body of flesh, blood, and bone, but personality. Man's self-conscious prescience constitutes the unique characteristic of something that has emerged from the flux of life's stream. To have lost this in one's "process of realization" and to have gained the whole world would have profited nothing.

In emphasizing the prescience of animals, I do not wish to be understood as postulating something that stands counter to unity of the cosmic process. What I have said has been given by way of emphasizing that the outstanding fact of the universe to me is my self-consciousness, a conspicuous attribute of which is my ability to look into the future. The cosmic process in me has come to be personal, not impersonal. So far as I can learn, life has never before been raised to the level of the self-conscious to the degree in which I find it in my fellow men and myself. Further, in man, life seems to find its fullest realization only through moral effort. Man is no longer an animal that lives by bread alone. Biology, therefore, lays a foundation for the most that faith prompts us to hope for and we may be justified in naming the name eternity.

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